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Measurement Techniques

(The Soviet Journal *Izmeritel'naia Tekhnika* in English Translation)

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NEW ACHIEVEMENTS IN MEASUREMENT TECHNIQUE

The decision of the Soviet Government to increase control over measurement technique and to take measures for securing uniformity and precision of measures and measuring instruments used in the USSR, and the resolutions of the Twentieth Congress of the Communist Party of the Soviet Union on development of the instrument-making industry, placed tasks of great responsibility on Soviet metrologists and instrument makers.

The year 1958, which has just started, is a year of completion of work: on the basis of improvements in the operation of the metrological institutes and government measurement control laboratories, it is expected that during this year the country's bureaus and services on measures and measuring instruments will get rid of the lag prevailing in several phases of measurement technique, and will assure full and satisfactory care for all metrological needs of the country's national economy.

At the end of last year the Committee on Standards, Measures and Measuring Instruments approved plans for government standardization and scientific research projects for the Committee's institutes in 1958.

In the area of government standardization of measuring techniques, the principal efforts in 1958 will be directed toward preparation and approval of standards, which will improve the important qualities of measuring instruments – accuracy, dependability, long service life, stability, and resistance to external influences. Most serious attention will be paid to establishment of well substantiated typing and parameter classification of instruments, the object being to eliminate unjustified multiplicity in design of instruments serving the same purpose. There also will be developed standards for new instruments, particularly in the fields of radio measurements and dosimetry, which are being standardized for the first time.

A large amount of work is planned in the area of standardization of the most modern automatic measuring instruments used in automation of industrial processes. The projects include standardization of electronic potentiometers, bridges, oscillographs, amplifiers, various automatic regulators, valves and transducers of aggregate unified control and regulation systems, standardization of devices for measurement of details in processing, and of other instruments.

There must be considerable headway made in our work on normalization and standardization of the basic elements of instruments, their interconnections and details of construction, in order to assure their coordinated mass production, which will decrease the cost and increase the quality of the instruments and also make them easier to repair. In the first place, in 1958 it is planned to standardize dial scales for weight-measuring instruments, manometer tubes, jewels for measuring instruments, pointers, cores and elastic suspensions for electrical measuring instruments, prisms and cushion pads for common-use balances, clock mechanisms for recording instruments, sensing elements (sylphon bellows) for fluid delivery and level indicators.

In the plans for the institutes of the Committee for 1958 are included more than 150 projects on measurements of various kinds.

In the field of linear measurements, the institutes will finish the perfection of the optical interference method of length measurement by cross-hatched scales, the development of an indicator of linear travel using the method of optical graticules, investigation of a long-distance measurement method by the use of microwaves in the millimeter range, etc. There also will be work going on on sensitive schemes and elements for automation of linear measurements in checking operations.

In the area of mechanical measurements, it is planned to complete the creation of model manometers for pressures up to 25,000 kg/cm^2, of measuring apparatus for calibration and checking of manometers with lower

limits of 10^{-*} and 10^{-11} mm Hg., also the creation of new model instruments for the measurement of hardness, including the measurement of hardness of metals at temperatures up to 1000°C.

During this year the institutes of this Committee will continue the development of methods and basic apparatus for checking of instruments that are used for measurement of variable pressures, work towards creation of a standard apparatus for forces up to 100 t** and of a model force-measuring machine up to 3000 — and a model dynamometer for high loads. Work will also be advanced on the measurement of vibrations at high values of effective acceleration.

In the area of temperature measurements, it is planned to conclude the development of the method of measuring temperature by radio emission, the creation of a radiopyrometer, of an objective spectropyrometer up to 2500°C for checking purposes, of a setup for checking of radiation pyrometers in the region of temperatures below 0°C (down to −100°C), and development of a method of checking technical-grade optical pyrometers by means of alternating current. Work will be going on on methods for obtaining stable temperatures below 10°K, on measurement of temperatures by infrared radiation, on measurement of flame temperatures up to 8000°C in nonstationary processes, on a series of thermodynamical measurements, and also on the development of the corresponding instrumentation.

In the field of electrical and magnetic measurements, it is planned to finish the development of methods and apparatus for checking of units and instruments for low resistances (to 10^{-6}) on direct current, for checking of total impedances up to 10^{5} ohms with an accuracy of the order of 1% at frequencies to 50 Mc, for measuring of small alternating currents from 20 μa to 1 ma in the region of sound frequencies, for the design of model units for capacitance measurements at frequencies from 50 Mc down to 1 cps, and other projects. During this year we will also finish several discrete stages in the development of methods and apparatus for exact magnetic measurements by the use of intra-atomic phenomena.

In the region of radio measurements, there will be produced an assembly of model apparatus for the measurement of power under continuous operating conditions in the frequency band from 150 to 40,000 Mc, also apparatus for the measurement of currents at ultrahigh frequencies, of resistances and parameters of radio-frequency channels, of momentary parameters of pulses, of field intensities, of interferences and of parameters of dielectrics.

In the field of time and frequency measurements, it is planned to finish the production of a group of standard quartz and molecular oscillators.

As a result of the development work on acoustical measurements, equipment for absolute measurements of ultrasound pressures will be produced.

In the realm of light measurements, our institutes in 1958 will carry out the development of color samples, of a color scale and of model apparatus for colorimetric measurements, and also of gas and luminescent lamps for reproduction of the unit of luminous flux.

In the area of ionizing radiations, it is planned to continue the standardization work and development of methods and devices for the checking of radiometric and dosimetric apparatus.

In the middle of 1957 the Bureau of Interchangeability in the metal-working industry was transferred to the jurisdiction of this Committee. In 1958 this Bureau will carry out a number of research, development, and experimental-design projects on automation of control operations in machine building, on creation of new kinds of measuring instruments based on new methods, and on raising the level of interchangeability in the machine-building industry.

For 1958 considerable advancement of international metrological efforts is planned, in particular towards organization of international metrological legislation, in which efforts the USSR participates by providing administrative and secretarial personnel for four technical committees and by holding membership in nineteen other technical committees.

The workers on measurements techniques in the government control laboratories face very responsible tasks. In 1958 these laboratories must change over to new forms of checking procedures.

Conferences of laboratory workers will be devoted to the examination and perfection of these procedures. At these conferences there will be presented and discussed reports on how the government resolution about

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* Omitted exponent in original Russian.

** Tons force

strengthening of control over measurement technique is being carried out, in order fully to make this resolution a reality; also, reports on research and development projects on metrology, on the work of the metrological institutes towards implantation of modern measurement techniques, and on the work of the government measurement control laboratories with regard to the reorganization of the industry's administration.

At the present time a great deal of work is in progress on the seven year plan of development of the USSR's national economy during the years 1959-1965. The new seven year plan will assure the further development of our country, and will contribute to the introduction in the national economy of new advanced techniques and technologies, and among them of a modern measurement technique.

LINEAR MEASUREMENTS

PLANNING AND LAYOUT OF LABORATORIES FOR LINEAR MEASUREMENTS

S. A. Kaplan

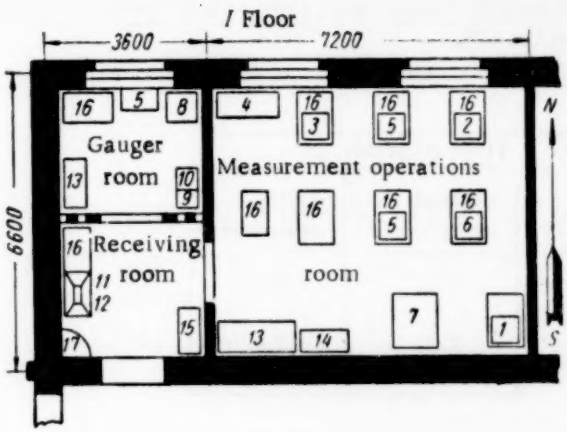
For the purpose of creation of standard specifications which could serve as guides when carrying out reconstruction of measurements laboratories or building of new ones, the Department of Measures and Measuring Instruments of VPTIStroiDorMash (the former Ministry of Building and Highway Construction Machinery) has worked out a typical problem of design of a measurements laboratory for industrial plants. In view of the absence of basic data for such standardization, first these and standard methods of calculation of derived data were worked out.

TABLE 1

No. of location on plan	Name	Quantity
1	Instrument microscope, large model	1
2	Optical length-measuring device, horizontal	1
3	Optical length-measuring device, vertical	1
4	Optical graduating head	1
5	"Minimeter" gauges for measurement of small deviations from standard dimensions on special stands	3
6	Instrument for determination of cleanness of surface	1
7	Flatness checking plate of 750 x 1000 mm area	1
8	Flatness checking plate of 450 x 600 mm area	1
9	Electric recorder	1
10	Device for demagnetizing of instruments	1
11	Exhaust hood	1
12	Electric heater plate	1
13	Instrument locker, 2350 x 1800 x 600 mm	1
14	Lockers for accessories and papers, 1800 x 1000 x 500 mm	2
15	Locker for clothing	1
16	Tables for instruments and work	10
17	Sink and water faucets	1

We have established a list of the minimum equipment for a plant engaged in small-batch or piece-by-piece production, employing quantities of measuring instruments of not over 2500 units, including those that are kept in the central store room of the plant. This list is given in Table 1. In the figure, we have shown a layout for location of this equipment in the laboratory rooms.

As a result of this planning and location of equipment, a standard of 3 to 3.5 m^2 for one working space was determined.



To determine the number of men needed for checking of the measuring devices, the standard time for checking of a unit measuring instrument or device was calculated. We took into consideration the time standards for checking which are in force at the base laboratory of the Department of Measures and Measuring Instruments of VPTIStroiDorMash, the actual time spent at some factories, and time standards given in some publications and, in particular, the standards of the S. Ordzhonikidze plant in Starokramator. In those cases when there was considerable digression between these data, the average of them was taken as a standard.

The selected time standards are set up for the complete checking of a unit of a universal measuring instrument or device, providing for all the work needed, including the paper work of recording the technical test data on the proper forms, oiling, paraffining of the devices, etc.

The following time standards for checking were accepted: for one universal measuring instrument (including instruments combining optical and mechanical means) 35 min; for one limiting gauge or template 15 min; and for a unit of a technological or control setup 90 min.

For exterior inspection (with merely occasional random checkup measurements) for a universal instrument, a standard time of 6 min was established, and for gauges and templates 5 min.

The mandatory number of periodic checkups is 6 times a year for every unit of a universal instrument, including 2 times a year after every repair. This makes the total time per unit instrument per year 210 min.

For periodic checkups of gauges and templates the established standard is 6 times a year for every unit, or 90 min per year.

In addition, it is assumed that every instrument kept in the Central Instrument Store (CIS) is subject to periodic checkups every three months, while all other measuring instruments are subject to exterior inspection and a checkup on the quality of their conservation and condition. For accounting and budgeting purposes, for all instruments kept in the CIS, a standard average time of 20 min per unit per year has been established.

For the frequency of check testing of technological and control setups, a standard of two times a year per unit has been set up.

As to the determination of the quantity of instruments which are to be checked by exterior inspection, it was established that according to the experience of a number of Moscow factories, the instrument inspection department of the factory receives, every day, about 5% of the total number of instruments and about 7% of the gauges and templates that are in general use. These figures are accepted now as a basis for accounting and budgeting purposes.

After the time standards have been established, the number of workers directly engaged in the checking operations is calculated by means of the following formula:

$$n = (0.17N_m + 2.67N_u + 1.7N_g + 1.59\ N_t)10^{-3},$$

where N_m is the number of units of measuring instruments kept in the CIS, N_u is the number of "universal" instruments in use, N_g is the number of gauges and templates in use, and N_t is the number of units of technological and control setups in use.

The coefficients 0.17, 2.67, 1.7, and 1.59 represent time standards for the checking of 1000 units of the corresponding measuring devices as figures relative to the total amount of the yearly working time of one worker, which is 2260 hr per year.

For approximate preliminary calculations of the required number of workers, the following simplified formula can be used:

$$n = 1.25N \cdot 10^{-3},$$

where n is the required number of workers, and N is the total number of measuring devices (for linear and angular measurements) present in the factory, including those kept in the CIS.

TABLE 2

Kind of measuring instrument	Time standards, hr		
	First complexity	Second complexity	Third complexity
Instruments with vernier	0.5	1.0	2.0
Instrument with micrometer screw	0.75	1.5	2.5
Indicating instruments	0.75	2.0	2.5

A statistical evaluation of data from 60 factories and plants, giving a distribution of their measuring devices among different categories, showed that the measuring devices which are kept in the CIS (N_m) constitute about 40% of the total present in the factory; the 60% that are in actual use in production are divided into the following categories: universal instruments – 10% (N_u), gauges and templates – about 40% (N_g), and technological and control setups – about 10% (N_t).

In order to test how satisfactory the above-proposed formula for the required number of checking workers is, we calculated the number of workers required for each of 60 factories and compared it with the number of workers actually employed on this task by that factory.

This comparison showed that for 50% (31 factories) the calculated number of workers completely coincided with the number actually employed, for 13% (8 factories) the calculated number was lower than the number of actually employed men; for 37% the calculated figure was somewhat higher than the actual (by not more than 20 to 25%).

Thus, the proposed approximate formula for the number of workers required for checking operations is sufficiently satisfactory and can be recommended for practical use.

According to established practice, it is accepted that each unit of measuring device which is in actual operation is subjected to repair once a year. This repair work is divided into the following categories as to the kind and volume of work involved: ordinary everyday run of repair work (first degree of complexity) – 100% of instrument units; average repair work (second degree of complexity) – 40% of units, and capital repair (third degree of complexity) – 15% of units.

The universal measuring instruments which are in use are subdivided according to their construction into the following categories: measuring instruments with vernier – 50%, with micrometer screws – 30%, and indicating instruments – 20%.

In Table 2 the average time standards for repair of a measuring instrument are given; these were established on the basis of averages from actual working times spent on such operations according to the experience of the base laboratory of the Department of Measures and Measuring Instruments of VPTIStroiDorMash.

Taking into account the above-described conditions, and adding 10% for unforeseen work, the number of gauger-machinists is determined by the following formula:

$$n = 0.75N \cdot 10^{-3},$$

where N is the quantity of measuring instruments subject to repair, and 0.75 is a coefficient which represents the time standard for repair of 1000 instrument units figured as a ratio to the total yearly working hours of a gauger-machinist.

The above approximate formula was tested by three years' experience of the base laboratory of the Department of Measures and Measuring Instruments of VPTIStroiDorMash and showed sufficiently good agreement with practice (the discrepancies are not over 10%).

The above minimum list of equipment and laboratory layout, basic standards for calculation, and approximate formulas should be corrected according to actual conditions prevailing at individual plants.

MEASUREMENT OF WORKING SURFACE OF CONOIDS BY COMPARISON WITH SPECIMEN

A. V. Rumiantsev

In modern computing mechanisms and control instruments, conoids are widely used for the mechanical reproduction of functions of two independent variables.

At the present time the measurement of the working surface of conoids is mainly effected either by the absolute measurement of the radius vectors at points according to a working table, or by comparison with a conoid master form.

The absolute method of measurement differs only from the finishing of a working surface by the point method in that a layer of metal is not removed, and it possesses all the faults inherent to treating a surface by the point method.

The main fault of this method is its great laboriousness, since the checking may require, according to the size of the conoid, as much as 4000 measurements, and the necessity for high-precision equipment demanding very accurate adjustment.

Measurement by points cannot give a true picture of the accuracy of working at all points of the working surface, especially at points with large lift angles, despite the absolute necessity for this in view of the fact that, in the operation of a conoid mechanism, the follower travels not only over those points given by the table, but arbitrarily over the whole surface in a wide range of variation of the independent variables $\underline{x}$ and $\underline{y}$ in the reproduction of the function $z = f(x,y)$.

The measuring error depends on the error Δh in measuring the radius-vector at a given point, on the error $\Delta\varphi$ in turning the conoid through the angle of rotation, on the error Δl in moving the conoid along the axis, on the existence of eccentricity of the mandrel, and eccentricity due to the play between the mandrel and the conoid hole, as well as on other errors (skewness of ends, inaccurate setting of conoid in initial position, etc.), which are difficult to estimate and which make a very small contribution to the total error ΔR.

Thus, the error in measuring the working surface of conoids by the point method is mainly determined by the following equation:

$$\Delta R = \Delta h + R\Delta\varphi \operatorname{tg}\alpha_\varphi + \Delta l \operatorname{tg}\alpha_l + \Delta R_{\Delta e}, \tag{1}$$

where R is the radius-vector, α_φ is the lift angle of the working surface in a plane perpendicular to the axis of rotation of the conoid, α_l is the lift angle of the working surface in a plane passing through the axis of rotation of the conoid, and $\Delta R_{\Delta e}$ is the eccentricity error.

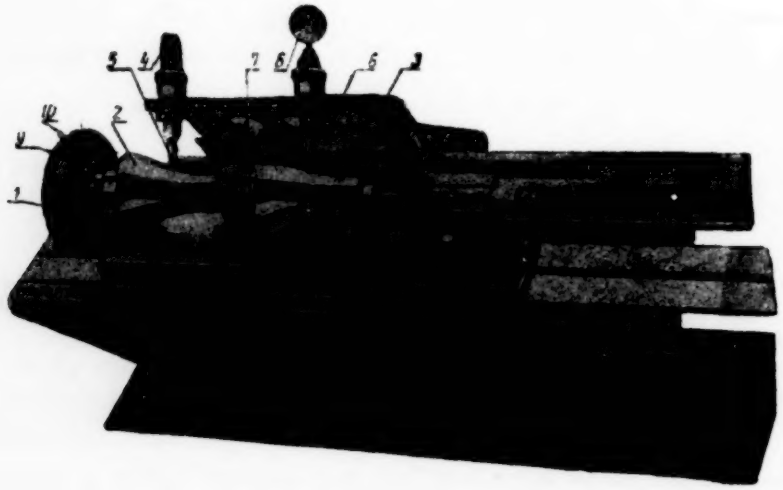
The eccentricity error is given by the equation:

$$\Delta R_{\Delta e} = \frac{1}{\cos\alpha}\cos(\theta + \varphi + \alpha)\Delta e, \tag{2}$$

where α is the total lift angle of the working surface, φ is the angle of rotation, θ is the angle of eccentricity relative to the initial position of the conoid, and Δe is the eccentricity.

As we see from (1) and (2), the measuring error, besides depending on the errors $\Delta R_{\Delta e}$, Δh, $\Delta\varphi$ and Δe, depends to a great extent on the lift angles of the working surface and the size of the radius-vector at each point of the working surface, and thus represents a variable value in the limits of measurement of the same conoid.

A calculation of the error in measuring conoids by the probability theory method from (1) shows that, for measuring the radius-vector of the working surface of a conoid with lift angle more than 40° and R > 50 mm with vector error $\Delta R = 0.01\text{-}0.025$, the angle of rotation must be set to an accuracy of 10", and the lengthwise shift to within 0.005 mm. Hence, for measuring conoids, especially with large lift angles and radii, we require frames and instruments with accurate dividing heads and reading microscopes.



To estimate the actual accuracy of finishing a working surface by manual lapping and the point method, we carried out measurements by comparing several conoids, allowing 0.05 mm on the radius-vector worked by manual lapping, measured by points and accepted by OTK.* These measurements showed that the scatter of sizes had wide limits and only as the lift angle diminished did the deviations approximate to those given.

This is due to the fact that the accuracy in measuring the working surface by the point method is affected by the lift angle and the variable value of the radius-vector, as well as by the inaccuracy of finishing due to the presence of hills and valleys between the points, in the case of manual lapping.

While in measurement by points, the gauge is set at the points given by the working tables, where the surface is brought within the limits allowed, in measurement by comparison, the gauge is set near the points or between them, where hills and valleys are present.

Thus, the point method of measuring conoids cannot be recommended for the serial production of conoids.

Though the measurement of conoids by the usual method of comparison is very efficient, it requires high-precision machines, their exact and very tedious adjustment, and also exact master forms and highly-skilled operators.

We describe below a new method of measuring conoid surfaces by comparison with a specimen, which is not only very efficient, but is also free from the faults of the usual comparison method.

The essence of the new method of measurement by comparison with a specimen is as follows.

On a special machine (see Figure) designed for measuring the working surface of conoids by the comparison method, a copy 2 is mounted on the headstock 1, flush with the mandrel, and on the other mandrel on the right – a specimen 3, in place of the conoid to be measured. For reducing the effect on the accuracy of measurement of hills and valleys between the points, the working surface of the specimen is worked by points from a fuller table, in which at regions with large radii and lift angles of the conoid ($\alpha > 30°$), the step of the angle of rotation is set at 1-1.5°, and the step of travel of the conoid along the axis is l = 1-1.5 mm.

The specimen is worked on a precision machine equipped with accurate optical dividing heads and reading microscopes for measuring R and l.

*Board of Technical Control.

After machining the working surface of the specimen,we measure it by the point method on an accurate instrument, and then the specimen is set in a model or instrument and finally tested by the repeated solution of several problems in a wide range of the independent variables. If the instrument with the given specimen gives good results to all the problems and there are no deviations surpassing the permissible, the specimen is passed, and its accuracy taken as the lowest limit.

In order to reduce the effect on the measuring accuracy due to the wear of the gauge and roughness of the working surface , the copy and specimen are worked to the 8th class of finish by lapping and polishing. The unevenness of the working surface of the copy and the presence of roughness has a considerable effect on the accuracy of measurement by the comparison method. The specimen for measurement was the same one from which the copy was made on a copy-milling lathe.

Before measurement of a particular type of conoid the machine is adjusted and this adjustment is periodically repeated to check the accuracy of setting.

First we set the mandrels with the copy and specimen center plates, which are made to the 1st class of accuracy with radial play of 0.005 mm. The mandrels are set coaxially and parallel to the guide carriage. This is checked by means of an indicator fastened to the cylindrical part of the gauge holder 4. With this method of measurement,we do not require the high parallelism demanded by the usual comparison method, and a ± 0.02 mm deviation from parallelism is permissible on a length of 120 mm.

After setting the mandrels we check the positions of the gauges 5 and 6 in the vertical and horizontal planes with an indicator attached to a stand in an $\perp$-shaped slot of the table, by moving the carriage and bringing the gauges in turn to the indicator. In this case, the floating gauge 6 is locked by a clamp, and gauge 5 is rigid. Then we mount the copy 2 and the specimen 3 and verify their position with respect to the axis by bringing the gauges to the end faces with the greatest radii. The gauge is brought up to the specimen so that it makes full contact with the latter; for this we select a spacing ring of appropriate width, this being set on the mandrel and used for testing all the conoids of that type.

After this the gauges are set on the cylindrical part of the center plates 7, which have equal diameters, and the scale of indicator 8 is set in the zero position.

It should be noted that this method of measurement does not make high demands on the accuracy of adjusting the machines, since in the measurement of serial conoids, as will be seen from the later account, allowance is made for the error of the machine, instrument and copy of the specimen.

In measuring the working surface of accurate conoids with large lift angles ($\alpha > 30°$), the indicator 8 is extremely sensitive to small changes of position of the conoid, and hence in such cases it is desirable to adjust the machine with greater precision.

After setting the machine and mounting both conoids,we measure the deviation of the copy from the specimen. By rotating the handwheel 9, which is rigidly connected by a clamp with the mandrel of the copy, we rotate the copy and the specimen from the initial position through an arbitrarily chosen angle differing from the table angle. The angle of rotation from the initial position is read from the indicator 10 against the circular scale of the handwheel, which is divided into 360°.

By turning the copy and specimen in the range of the working part through arbitrarily chosen angles of rotation, we record the deviation of the indicator at each point in a special table. After measuring the deviation of the copy from the specimen at points on the first section,we move the carriage with the gauge to another arbitrarily chosen section differing from the table value, and again rotate the copy and specimen through the same arbitrarily chosen angles as in the first section, and record the deviations of the indicator, and so on.

For obtaining the actual value of the deviation of the copy from the specimen,this measurement is made three times by removing the specimen from the mandrel and setting it again on the machine. The arithmetic mean of these measurements determines the error of the position of the specimen on the machine, which depends mainly on the eccentricity Δe, created by the play between the mandrel and the specimen hole.

The deviation of the copy from the specimen represents the total error due to the errors of the machine and its adjustment, the instrument errors, the error in making and setting the copy, and the error in setting the specimen.

Measurement No.	Total error of machine, instrument, copy, and setting of specimen TE, $\Sigma(\Delta c + \Delta u + \Delta k + \Delta y_0)$	Indicator readings in measuring section of conoid IR	Actual error of machining serial conoid ΔR
1	0.015	0.035	0.020
2	0.020	0.045	0.025
3	0.030	0.060	0.030
4	0.045	0.085	0.040

After determining the total error of the machine, instrument, and copy, the specimen is removed from the machine and a serial conoid is mounted in its place. Then we measure it in the same way as we measured the total error from the specimen, and the results of measurement are plotted on the table. To avoid the result being affected by the eccentricity of the mandrel, the latter is set by means of a flat rod or other fixing element in the position at which the specimen was set.

In machining the working surface of conoids by the method of copying from a specimen, measurement is made at 3-10% of the points, mainly at regions with large lift angles.

After measuring the total error of the machine, instrument, and copy, the position of the indicator is maintained, since a change of the latter would give erroneous results in measuring the serial conoids.

The actual error in machining a serial conoid produces the difference between the indicator readings in measuring a particular conoid and the total error of the machine, instrument, copy and the error in setting the copy and specimen, as shown in the table. This is explained by the fact that in measuring a serial conoid the indicator reading includes, besides the error in making the conoid, the sum of errors of the machine, instrument, copy, and error in setting the conoid and specimen.

Thus, the actual error in making a serial conoid is estimated from the equation:

$$\Delta R = IR - TE = \Delta R_{IR} - \Sigma(\Delta c + \Delta u + \Delta k + \Delta y_0).$$

The error of the machine Δc, the instrument Δu, the copy Δk, and the error in setting the copy and specimen Δy_0 cannot be estimated separately, and this particular method of measurement does not require it.

We must note that the error ΔR, besides the error in machining the working surface, includes the error in setting the conoid on the machine, which depends mainly on the play between the conoid hole and the mandrel.

The new method of measuring the working surface by comparison has great advantages over the point method of measurement and the usual method of comparison.

SUMMARY

The main advantages of the new method of measurement include the following.

1. Approximation of the conditions of measurement to the conditions of operation of a conoid and follower in a real conoid mechanism, since the gauge moves arbitrarily over the working surface and may be found at any surface point not given by the coordinates of the working table.

2. Great efficiency of measurement, 10-15 times better than measurement by points.

3. Possibility of preparing interchangeable conoids.

4. High precision of measurement due to exclusion of the errors of the machine, instrument, preparation and setting of the copy, and also the exclusion of mandrel eccentricity.

5. It does not require precise and expensive machines and instruments with optical reading devices.

6. Possibility of measuring eccentrics, screws with nonuniform pitch, and other complex components.

INTERFEROMETRIC METHOD OF MEASURING ANGLES OF POLYHEDRONS

L. N. Logacheva

Angular standards in the form of rectangular prisms (polyhedrons) are widely used today in industry because they have a number of advantages with respect to single-angle standards. The presence of several working angles in the polyhedron decreases the time of preparation for measurement, and in the end speeds up the whole process of measurement; the closed contour of the polygon allows an increase of precision in measuring the angles of polyhedrons.

At the present time angles of polyhedrons are measured mainly by goniometric methods whose maximum precision does not exceed 1". With more precise autocollimation methods the angles of polyhedrons can be measured with a precision higher than 1".

The interferometric method of measuring small angles (up to 2'), described below, allowed us to measure the angles of polyhedrons with a precision of the order of 0.2", using Kesters' interferometer.

When the angular standard is lapped by one of its faces to the flat plate placed in the proper position on the table of the apparatus one can see in the field of vision two systems of interference fringes of different widths, one corresponding to the free working surface of the angular standard, and the other to the plate. If one presses on the jacket of the telescope of the instrument, one creates a certain amount of rotation of the reference plane in the field of vision, and as the result the interference fringes are displaced; the character of this displacement of the interference fringes depends on the relative position of the planes of the angular standard and the support mirror. Two different cases may occur: either the displacement of the fringes on the standard and on the plate are in the same direction, to the right or to the left (Fig. 1), or the displacement occurs in opposite directions (Fig. 2).

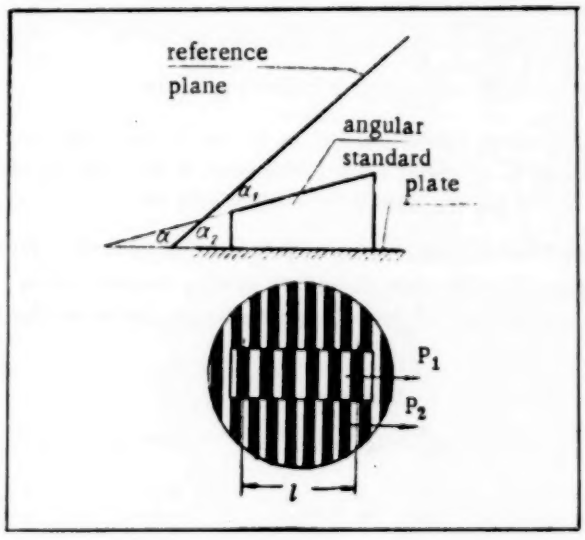


Fig. 1

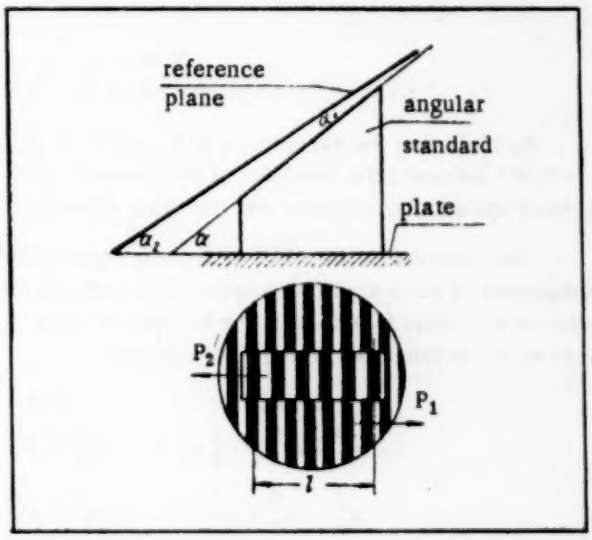
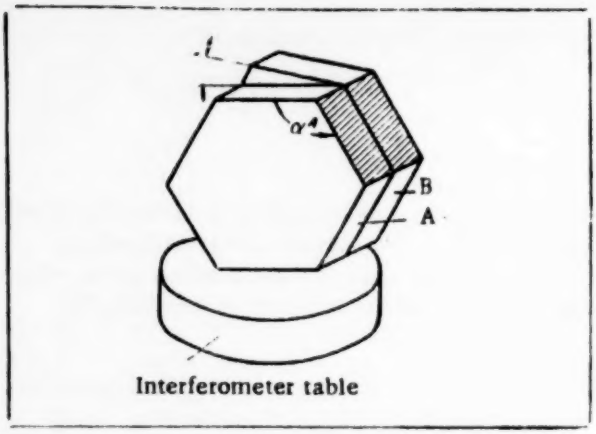


Fig. 2

When the interference fringes on the standard and on the plate move in the same direction, the magnitude of the angle α of the standard is calculated by the expression:

$$\alpha = \alpha_2 - \alpha_1 = \frac{\lambda}{2l}(n_2 - n_1), \qquad (1)$$



Interferometer table

Fig. 3

and when the fringes move in opposite directions the angle is calculated by the expression:

$$\alpha = \alpha_2 + \alpha_1 = \frac{\lambda}{2l}(n_2 + n_1). \qquad (2)$$

where n_1 is the number of interference fringes counted over the length l of the standard, n_2 is the number of interference fringes counted over the length l of the plate, l is the length perpendicular to the direction of the interference fringes, and λ is the wavelength of the light ray. In its general form, the equation giving the value of the angle α can be written as follows:

$$\alpha = \frac{\lambda}{2l} n, \qquad (3)$$

where $n = n_2 \pm n_1$.

The magnitudes of n_1, n_2 and l can be conveniently measured with a micrometer equipped with an eye piece with a reticle carrying vertical lines perpendicular to two horizontal lines. The horizontal displacement of these lines can be achieved by rotating the drum of the micrometer.

The micrometer with its eye piece is placed in front of the telescope of the apparatus. In order to make the interference picture coincide with the plane of the reticle of the micrometer, an auxiliary lens is placed beyond the slit of the interferometer. This type of counting arrangement insures the measurement of the magnitude of l with a precision of 0.1 mm, and the magnitude of $n = n_2 \pm n_1$ with a precision of the order of 0.05 of the width of the fringe.

The precision of the interferometric method of measurement of the angle can be calculated by differentiating Eq. (3) with respect to two variables, n and l :

$$\delta\alpha = \pm \sqrt{\left(\frac{\lambda}{2l}\,dn\right)^2 + \left(\frac{n\lambda}{2l^2}\,dl\right)^2} \qquad (4)$$

By replacing the parameters of Eq. (4) with the corresponding numerical values ($n = 6$, $l = 15$ mm, and $\lambda = 0.587$ microns), the precision of the measurements is found to be about $\pm 0.3''$. However, if the working surfaces of the angular standard and the plate are not plane, and if the standard is pyramidal, the error increases.

The described method of measuring angles can be used for the calibration of polyhedrons by consecutive comparison of each angle of polyhedron A with all the angles of polyhedron B, and by solving a system of m series of equations (where m is the number of faces of the polyhedron, α_1^A and α_1^B are the angles between the faces of the polyhedrons A and B) of the type:

Series I	Series II	Series m
$\alpha_1^A - \alpha_1^B = \omega_1^I$	$\alpha_2^A - \alpha_1^B = \omega_1^{II}$	$\alpha_m^A - \alpha_1^B = \omega_1^m$
$\alpha_1^A - \alpha_2^B = \omega_2^I$	$\alpha_2^A - \alpha_2^B = \omega_2^{II}$	$\alpha_m^A - \alpha_2^B = \omega_2^m$
. . . . .	. . . . .	. . . . .
. . . . .	. . . . .	. . . . .
. . . . .	. . . . .	. . . . .
$\alpha_1^A - \alpha_m^B = \omega_m^I$	$\alpha_2^A - \alpha_m^B = \omega_m^{II}$	$\alpha_m^A - \alpha_m^B = \omega_m^m$

Solving this system of equations by the method of least squares, one determines the values of the angle α of the polyhedrons from the equation:

$$\alpha_1^A = \frac{\sum_1^m \omega_i^{\mathrm{I}} + 180(m-2)}{m}; \quad \alpha_2^A = \frac{\sum_1^m \omega_i^{\mathrm{II}} + 180(m-2)}{m} \quad \text{etc.}$$

$$\alpha_1^B = \frac{(\omega_1^{\mathrm{I}} - \alpha_1^A) + (\omega_1^{\mathrm{II}} - \alpha_2^A) + \ldots + (\omega_1^m - \alpha_m^A)}{m};$$

$$\alpha_2^B = \frac{(\omega_2^{\mathrm{I}} - \alpha_2^A) + (\omega_2^{\mathrm{II}} - \alpha_2^A) + \ldots + (\omega_2^m - \alpha_m^A)}{m} \quad \text{etc.}$$

The precision of the results of a single measurement of the angle can be characterized by the value:

$$\sigma = \pm \sqrt{\frac{\sum_1^m v^2}{m^2 - m}}$$

The limit precision of the result of measurements of the angle is equal to:

$$S = 3\sqrt{\frac{\sum_1^m v^2}{m(m^2-m)}};$$

where $\sum_1^m v^2$ is the sum of the squares of the remaining errors.

We have calibrated two steel hexahedrons by this method, on a vertical Kesters' interferometer by using the yellow light of helium as light source.

In order to compare the angles α^A and α^B each polyhedron was lapped to the glass plate by one of its faces, creating a corresponding angle, and the interference fringes appearing in the field of vision due to the free faces of the angles α^A and α^B served to determine the value of ω.

Figure 3 represents diagrammatically the position of the polyhedrons on the table of the apparatus during the measurement of the angle ω. The faces lapped to the glass plate are represented by hatched lines (the plate is not shown in Fig. 3). The measurement of ω was made twice for two different lappings, and the arithmetic mean of the values obtained was taken as the result.

The limit of precision of the results of measurement of the angle was of the order of 0.2".

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MEASUREMENT OF THE ECCENTRICITY OF ARTICLES MOUNTED AT THE CENTER

A. D. Rubinov

One of the most widely used methods of determining the eccentricity of cylindrical articles (smooth or stepped shafts) is that of measuring the radial variation with the help of an indicator. The article, mounted at the center, is turned under the tip of the indicator. The algebraic difference of the readings of the scale of the indicator (the swing of the pointer on the indicator) is taken to be twice the eccentricity.

TABLE 1

Figure	Indicator	Distance from cent. of rot. to tip and reading	Angle of rotation			
			$0°$ & $360°$	$90°$	$180°$	$270°$
1a	I	distance	$R-e\sin\alpha$	$r+e\cos\alpha$	$R+e\sin\alpha$	$r-e\cos\alpha$
		reading	0	$-\left[\frac{\Delta}{2}-e(\sin\alpha+\cos\alpha)\right]$	$2e\sin\alpha$	$-\left[\frac{\Delta}{2}-e(\sin\alpha-\cos\alpha)\right]$
	II	distance	$R+e\sin\alpha$	$r-e\cos\alpha$	$R-e\sin\alpha$	$r+e\cos\alpha$
		reading	0	$-\left[\frac{\Delta}{2}+e(\sin\alpha+\cos\alpha)\right]$	$-2e\sin\alpha$	$-\left[\frac{\Delta}{2}+e(\sin\alpha-\cos\alpha)\right]$
1b	I	distance	$r-e\sin\alpha$	$R+e\cos\alpha$	$r+e\sin\alpha$	$R-e\cos\alpha$
		reading	0	$\frac{\Delta}{2}+e(\sin\alpha+\cos\alpha)$	$2e\sin\alpha$	$\frac{\Delta}{2}+e(\sin\alpha-\cos\alpha)$
	II	distance	$r+e\sin\alpha$	$R-e\cos\alpha$	$r-e\sin\alpha$	$R+e\cos\alpha$
		reading	0	$\frac{\Delta}{2}-e(\sin\alpha+\cos\alpha)$	$-2e\sin\alpha$	$\frac{\Delta}{2}-e(\sin\alpha-\cos\alpha)$

TABLE 2

Figure	Dist. from the cent. of rot. to tip and reading	Angle of rotation				Max. difference in indicator readings
		$0°$ & $360°$	$90°$	$180°$	$270°$	
3a	distance	$r-e\sin\alpha$	$R+e\cos\alpha$	$r+e\sin\alpha$	$R-e\cos\alpha$	
	reading	0	$\frac{\Delta}{2}+e(\sin\alpha+\cos\alpha)$	$2e\sin\alpha$	$\frac{\Delta}{2}+e(\sin\alpha-\cos\alpha)$	$\frac{\Delta}{2}+e(\sin\alpha+\cos\alpha)$
3b	distance	$r+e\sin\alpha$	$R-e\cos\alpha$	$r-e\sin\alpha$	$R+e\cos\alpha$	
	reading	0	$\frac{\Delta}{2}-e(\sin\alpha+\cos\alpha)$	$-2e\sin\alpha$	$\frac{\Delta}{2}-e(\sin\alpha-\cos\alpha)$	$\frac{\Delta}{2}+e(\sin\alpha+\cos\alpha)$
3c	distance	$R-e\sin\alpha$	$r+e\cos\alpha$	$R+e\sin\alpha$	$r-e\cos\alpha$	
	reading	0	$-\left[\frac{\Delta}{2}-e(\sin\alpha+\cos\alpha)\right]$	$2e\sin\alpha$	$-\left[\frac{\Delta}{2}-e(\sin\alpha-\cos\alpha)\right]$	$\frac{\Delta}{2}+e(\sin\alpha+\cos\alpha)$
3d	distance	$R+e\sin\alpha$	$r-e\cos\alpha$	$R-e\sin\alpha$	$r+e\sin\alpha$	
	reading	0	$-\left[\frac{\Delta}{2}+e(\sin\alpha+\cos\alpha)\right]$	$-2e\sin\alpha$	$-\left[\frac{\Delta}{2}+e(\sin\alpha-\cos\alpha)\right]$	$\frac{\Delta}{2}+e(\sin\alpha+\cos\alpha)$

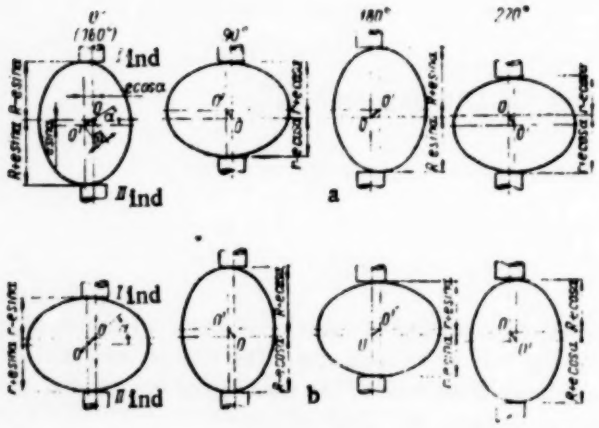


Fig. 1

This method of determining the eccentricity is invalid, because the radial variation is due not only to the eccentricity (noncoincidence of the geometrical axis with the axis of rotation), but also to the deviation from circularity (most frequently, the cross section may be considered an ellipse – we shall speak in terms of its "ovalness").

It is indicated in the literature that two indicators, rather than one, are needed for the separate determination of the eccentricity and ovalness, thus complicating the measuring procedure.

However, this method of determining the eccentricity, as half the difference of the two indicator readings, is valid only for the particular case

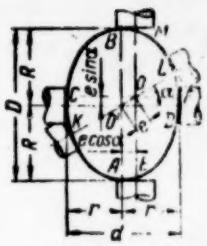


Fig. 2

when the center of rotation lies on one of the two axes of the ellipse.

In the general case, when the center of rotation does not lie on an axis, it is necessary to use a more complicated formula.

To show this, let us look at Fig. 1 and Table 1. In Fig. 1 a sequence of positions is shown corresponding to rotations of the article through successive angles of 90°; in (a) the indicator is set to zero at the highest point, and at the lowest point in (b);* Table 1 lists the distances from the center of rotation to the tip of the indicator and the readings of the scale of the indicator for each position of the article. As is evident from Table 1, in no case is the difference of indicator readings, when the article is rotated through any angle, equal to twice the eccentricity.

However, as will be shown below, the eccentricity may be determined, though not directly, when only one indicator is used.

In Fig. 2, a cross section of an article having ovalness $\Delta = D - d$ and eccentricity $e = 00'$ is shown. The maximum distance from the center of rotation to the tangent plane (to the flat surface of the tip of the indicator) can be either OE or OK, and the minimum is either OF or OL.

Three cases are therefore distinguished:

Case 1. OE > OK, and OF < OL. The article then has 4 critical points A, B, C, and D (points where the reading has a relative maximum or minimum). Two of these (A and B) are on the major axis of the ellipse, and 2 (C and D) on the minor axis. When the article is turned through 360° under the tip of the indicator, two maximum and two minimum readings are seen, and in general (when the center of rotation does not lie on either axis), the two maxima and the two minima are not equal to each other. This indicates that the ovalness has a larger value than the eccentricity ($\Delta/2 > e$).

In Fig. 3, four sequences of positions of the article are shown when it is rotated through various angles; the indicator is set to zero at the lowest point in (a) and (b), at the highest point in (c) and (d). The distance from the center of rotation to the tip of the measuring indicator, and the reading on the scale of the indicator for each position shown in Fig. 3 is entered in Table 2. From the data in Table 2 we conclude the following: a) the variation of the indicator reading is not equal to twice the eccentricity; b) the magnitudes and signs of the readings on the scale of the indicator when the article is rotated 90, 180, 270 and 360° depend on the position of the center of rotation relative to the geometrical center (on the angle α) and on the initial position of the article; c) when the indicator is set to zero at the lowest point (Fig. 3a, b), the readings are positive, and when at the highest point (Fig. 3c, d), they are negative, so it is recommended that the zero point be the lowest; d) the magnitude of the eccentricity may be determined from the triangle OO'K (Fig. 3a):

$$e = OO' = \sqrt{OK^2 + O'K^2};$$

$$OK = e\sin\alpha = \frac{a_{180}}{2};$$

$$O'K = e\cos\alpha = \frac{a_{90} - a_{270}}{2},$$

where a_{90}, a_{180}, a_{270} are the readings on the indicator scale when the angles of rotation are respectively those three angles.

Therefore,

$$e = \frac{1}{2}\sqrt{a_{180}^2 + (a_{90} - a_{270})^2};$$

e) to determine the ovalness one adds (algebraicly) the readings a_{90} and a_{270}, and deducts a_{180} from the sum

*In Figs. 1, 2, 3 and 4, 0 is the center of rotation of the article, and 0' is its geometrical center.

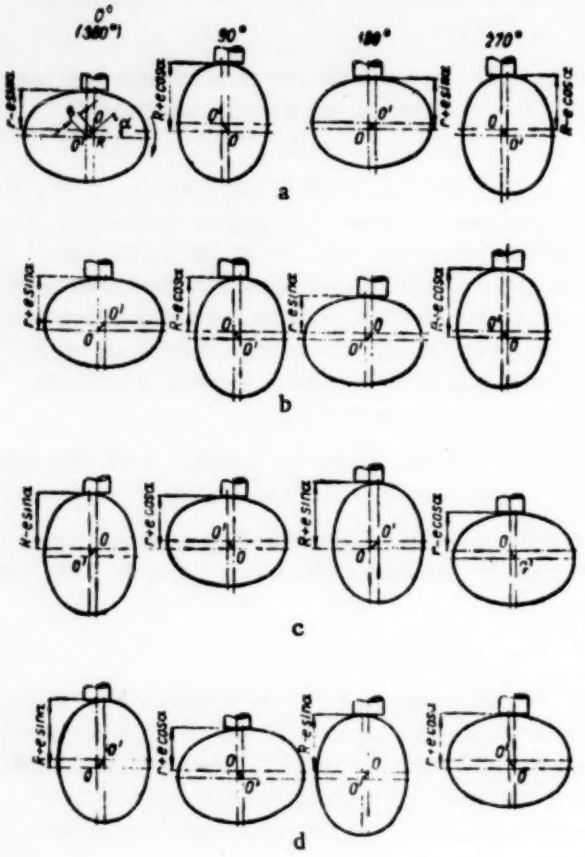


Fig. 3

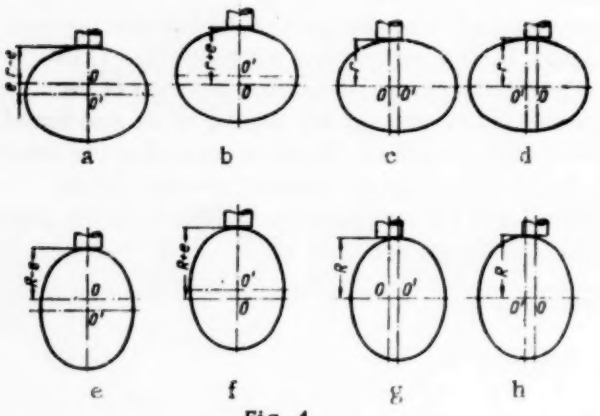


Fig. 4

TABLE 3

Figure	Distance from cent. of rot. to tip & read.	Angle of rotation 0° &360°	90°	180°	270°	Max. diff. in indicator readings
4a	distance	$r-e$	R	$r+e$	R	$\frac{\Delta}{2}+e$
	reading	0	$\frac{\Delta}{2}+e$	$2e$	$\frac{\Delta}{2}+e$	
4b	distance	$r+e$	R	$r-e$	R	$\frac{\Delta}{2}+e$
	reading	0	$\frac{\Delta}{2}-e$	$-2e$	$\frac{\Delta}{2}-e$	
4c	distance	r	$R-e$	r	$R+e$	$\frac{\Delta}{2}+e$
	reading	0	$\frac{\Delta}{2}-e$	0	$\frac{\Delta}{2}+e$	
4d	distance	r	$R+e$	r	$R-e$	$\frac{\Delta}{2}+e$
	reading	0	$\frac{\Delta}{2}+e$	0	$\frac{\Delta}{2}-e$	
4e	distance	$R-e$	r	$R+e$	r	$\frac{\Delta}{2}+e$
	reading	0	$-(\frac{\Delta}{2}-e)$	$2e$	$-(\frac{\Delta}{2}-e)$	
4f	distance	$R+e$	r	$R-e$	r	$\frac{\Delta}{2}+e$
	reading	0	$-(\frac{\Delta}{2}+e)$	$-2e$	$-(\frac{\Delta}{2}+e)$	
4g	distance	R	$r-e$	R	$r+e$	$\frac{\Delta}{2}+e$
	reading	0	$-(\frac{\Delta}{2}+e)$	0	$-(\frac{\Delta}{2}-e)$	
4h	distance	R	$r+e$	R	$r-e$	$\frac{\Delta}{2}+e$
	reading	0	$-(\frac{\Delta}{2}-e)$	0	$-(\frac{\Delta}{2}+e)$	

$$\Delta = a_{90} + a_{270} - a_{180}.$$

In the particular cases when the center of rotation lies on one of the axes of the ellipse ($\alpha = 0°$ or $90°$), the calculations involved in determining e and Δ are simpler.

Figure 4 shows the different possible positions of the geometrical center relative to the center of rotation when the indicator is set to zero, and the readings for various angles of rotation of the article are entered in Table 3.

From Table 3 we see that the magnitude of the reading after a rotation of 180° is either zero (when $\alpha = 0$) or $2e$ (when $\alpha = 90°$).

For $a_{180} = 0$ . . . . $e = \frac{a_{90} - a_{270}}{2}$, and $\Delta = a_{90} + a_{270}$.

For $a_{180} \neq 0$. . . . $e = \frac{a_{180}}{2}$, and $\Delta = a_{90} + a_{270} - a_{180}$.

If the article has only ovalness (eccentricity is absent), then the reading after a rotation of 180° is zero, and the readings after rotations of 90 and 270° equal half the ovalness ($a_{90} = a_{270} = \Delta / 2$).

Case 2. OE < OK, and OF > OL (see Fig. 2). The article has two critical points K and L, lying on the straight line through the centers O and O'. In this case $e > \Delta/2$.

When the indicator is set to zero at the lowest point (L) or at the highest point (K) the magnitude of the reading after rotation of 180° is twice the eccentricity:

$$R' + e - (R' - e) = 2e, \text{ where } R' = O'K = O'L.$$

From this, $e = a_{180}/2$.

Case 3. OE > OK, and OL < OF or OK > OE and OF < OL (See Fig. 2). The article has two critical points E and L or R and D, offset from one another.

To determine the eccentricity, it is necessary to set the indicator to zero first at the lowest, and afterwards, at the highest point; in both cases turn the article through 180° and take readings. The larger of the two (in absolute value) is twice the eccentricity. This is verified by observing that when the indicator is set to zero at E the reading after rotation through 180° is $OE - OM = R + e\sin\alpha - (R - e\sin\alpha) = 2e\sin\alpha$, and when set at L the reading is $OK - OL = 2e$.

In the same way, when the points K and F are used, readings of 2e and $2e\cos\alpha$ are obtained. The larger reading in each case is 2e.

To determine the ovalness in Cases 2 and 3, one follows the usual procedure: the diameter of the article is measured in two perpendicular directions (approximate determination), or the article is turned under the indicator tip while resting on a fixed surface.

The steps in this method of determining the eccentricity with one indicator are the following:

1. The indicator should have a flat or knife-edged tip with diameter greater than twice the eccentricity.

2. The tip should be in contact with the surface of the article with a tightness corresponding to 1-2 turns.

3. The article is turned at the center and the indicator is set to zero at the lowest point (the pointer occupies the furthest left position).

4. By turning the article one determines to which of the three cases considered the article corresponds; for this the number of critical points and their positions are determined.

5. In the first case, readings are taken after rotations of 90, 180 and 270°, and the eccentricity is found from the formula:

$$e = \frac{1}{2}\sqrt{a_{180}^2 + (a_{90} - a_{270})^2}.$$

At the same time, the ovalness may be determined from the formula:

$$\Delta = a_{90} + a_{270} - a_{180}.$$

6. In the second case, the article is turned through 180° and the eccentricity is determined by the formula:

$$e = a_{180}/2.$$

7. In the third case the article is turned through 180° and a reading on the indicator scale is taken. Then the indicator is set to zero at the highest point, and again the article is rotated 180° and a reading taken. The eccentricity is determined by the formula:

$$e = a_{180\,\max}/2,$$

where $a_{180\,\max}$ is the larger of the two readings.

AN INTEGRAL METHOD OF DIVIDING THE CIRCLE

N. M. Barshtak, Z. Ia. Bykova, I. Iu. Klugman,
I. I. Kniazhitskii and M. P. Rashkovich

The accuracy of the readings from existing optical and mechanical measuring devices is determined by the accuracy of their manufactured parts. Therefore, to increase the accuracy of an angle measurement,one must increase the accuracy of these parts, thus adding to the cost of the apparatus.

The integral method described here to divide the circle into any number of equal parts permits a high accuracy without a proportionate increase in the accuracy requirements of the instrument's individual parts.

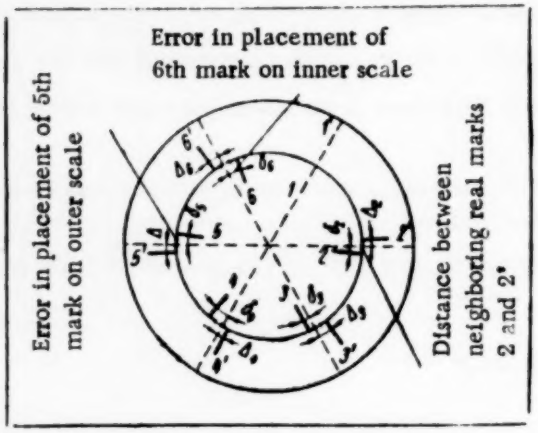


Fig. 1

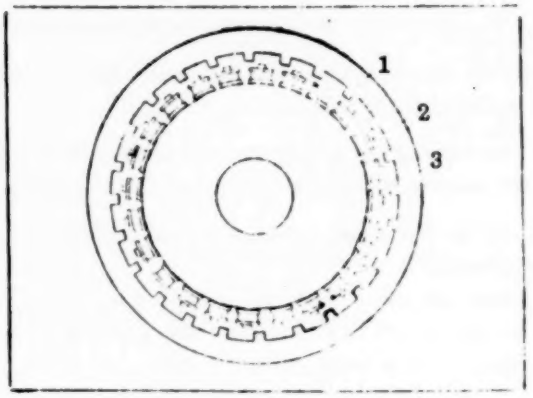


Fig. 2

The essence of the integral method is the following. Suppose we have two concentric circular scales divided by marks into n approximately equal parts (Fig. 1). The solid lines indicate the positions of these real marks, and the broken lines the positions of ideal marks which divide the circle exactly; here one of the ideal marks coincides with the real (marks 1' and 1 of the exterior and interior scales).

With existing optical and mechanical devices, to rotate the outer scale through an angle of $2\pi/n$,it is necessary to bring the mark 2' of the outer scale into coincidence with the mark 1 of the inner stationary scale; in doing so,the error will be equal to the error Δ_2 in the position of the placed mark 2'. Thus, in these cases, the largest error in angle reading is equal to the largest error in the marks placed on the outer scale.

In the integral method, however, a rotation through the angle of $2\pi/n$ is determined by an "integral" indicator which,in some sense,measures the sum of distances between neighboring real marks on the inner and outer scales (1 and 1', 2 and 2', etc.) When the ideal marks coincide, as is shown in Fig. 1, the sum of the distances between neighboring real marks ($1-1'$, $2-2'$, $3-3'$, etc.) is equal to the sum of the errors of the marks on the outer and inner scales $(\sum_{i=1}^{i=n}\Delta_i + \sum_{i=1}^{i=n}\delta_i)$. When the outer scale is rotated through the angle $2\pi/n$ exactly, the ideal mark 2' coincides with the mark 1, and all ideal marks of the two scales agree. The agreement of the ideal marks is the determining condition for the repetition of a reading on the "integral" indicator. Only when they coincide will the sum of the distances between neighboring marks on the two scales remain equal to the sum of the errors of the marks on both scales. Thus, with an "integral" indicator sensitive to the sum of distances between neighboring scale marks, the repetition of identical readings on this indicator will determine a rotation through the angle of $2\pi/n$, theoretically with ideal accuracy, independent of the accuracy of the marks placed on the scales.

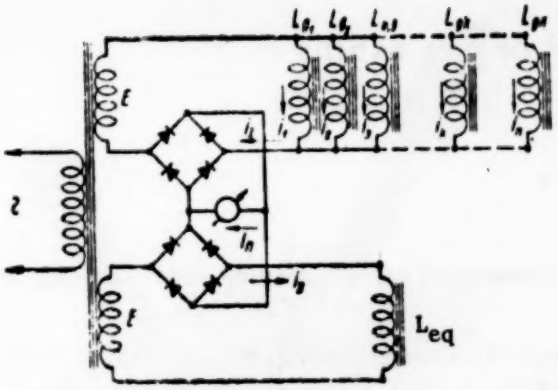


Fig. 3

"Integral indicators" may be made in the form of inductive, capacitive, photoelectric, and other systems.

An inductive dividing apparatus based on the integral principle is shown in Fig. 2. This device consists of an immovable core 1 with n teeth and a coil 2 mounted on each of them; and a rotating ring 3, also with n teeth. The windings of all coils are combined and included in a phase-sensitive network (Fig. 3). When ring 3 (Fig. 2) is rotated, the gaps between its teeth and those of the immovable core 1 change, which change appears as a change in the inductance of the "primary element" (upper right part of Fig. 3).

If an auxiliary inductance L_{eq} is used so that the indicator gives a zero reading when the ring is placed with its teeth and those of the core having their edges opposite each other, then when the ring is rotated through an angle of exactly $2\pi/n$, the indicator will again read zero. This is explained by the fact that the inductance of the primary element is the sum of the inductances of the coils, each of which, in turn, is proportional to the gap between the teeth. Clearly, this apparatus is of an integral type and the accuracy of the circle division does not depend on the accuracy of the placement of the teeth.

To verify this procedure, an experimental inductive-type integral apparatus for the division of the circle into 360 parts was examined. This apparatus was constructed in a simplified alternate way, differing from that described (Fig. 2) by the presence of one general coil encircling all n teeth. In this case the inductance of the primary element is no longer exactly proportional to the sum of gaps between neighboring teeth and, therefore, the errors in the construction of the cog-wheel will not be completely compensated for.

The parts of this measuring device had a known accuracy of the order of 4 minutes.

To increase the sensitivity of the scheme, the accuracy and stability of the pointer of the measuring part was brought about with a differential arrangement. Instead of an equivalent inductance (Fig. 3), a second primary element was included, having the same ring in common with the first, and a separate core offset one half step from the first.

In the differential arrangement, the rotation of the ring causes simultaneously an increase in the inductance of one primary element and a decrease in that of the second, with a resulting twofold increase in the sensitivity, compared to that of a nondifferential system.

The accuracy of the dividing apparatus was tested with a theodolite TV-1 for every 10° around the whole circumference, or, more thoroughly, every 2°.

As a result of the test it was established that the error in dividing the circle did not surpass 3.5 seconds. Thus, thanks to the use of the integral method even in its simplified alternate form, the reading error was less than $^1/_{60}$th the error of the manufactured parts of the measuring apparatus.

A higher accuracy (of the order of a fraction of a second) may be obtained even with the described simplified arrangement, by an increase in the accuracy of the manufactured cog-wheel (of the order of 0.5-1 minute), which still does not involve technological difficulties.

Also, the described inductive device may be simply, technologically, and inexpensively manufactured with ordinary slotting machines.

One significant advantage of this apparatus is the lack of contact between the measuring parts, thanks to which the accuracy of the results does not decrease with use.

AN OPTICAL DEVICE FOR THE MEASUREMENT OF THE RADIUS OF CURVATURE

A. I. Omel'chenko and A. V. Mokhov

This instrument is used in the control of small radii of curvature of edges of apertures which are made to a tolerance of ± 0.1 mm.

It is constructed on the principle of the double microscope [1]. A plane rectangular slit 3 (Fig. 1), 3.25 × × 0.04 mm in size, is illuminated by the lamp 1 and the condenser 2. Rays of light leaving the slit are reflected by the plane mirror 4 and are incident on the objective 5 which forms an image of the slit on the surface whose radius of curvature is required. This slit image passes through the point A in a direction perpendicular to the plane of the figure.

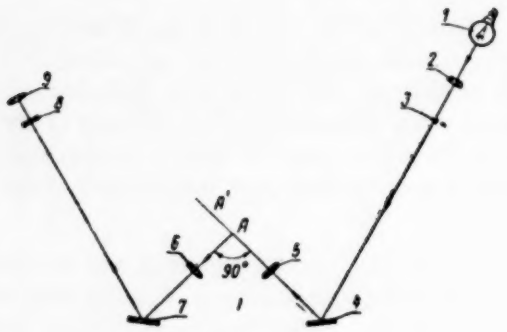


Fig. 1

As a result of the superposition of the slit image on the surface under investigation, one obtains a kind of "optical section" of the latter in the direction of the plane perpendicular to the figure and containing the points A-A'. If this "optical section" is observed in the direction perpendicular to A-A', then one sees the slit image in the form of an ellipsoidal arc. The slit image is projected by the microobjective 6 and the mirror 7 into the plane of the scale 8 which is subdivided in steps of 0.1 mm, and using the eyepiece 9, the sagitta of the arc can be measured against the background of the scale.

Using this sagitta, observed in the focal plane of the eyepiece, the radius of curvature of the surface may be calculated from the following formula

$$R=\frac{1}{2\beta}\left(\frac{x^2}{h\cos\varphi}+h\cos\varphi\right), \qquad (1)$$

where β is the magnification of the "optical section" of the surface in the focal plane of the eyepiece, x is the length of the half-chord of the arc, h is the sagitta of the image in the focal plane of the eyepiece, φ is the half-angle between the optical axes of the two tubes of the instrument (in Fig. 1, $2\varphi = 90°$).

Equation (1) was obtained from the well-known expression for the radius of curvature of a circular arc, $R=\frac{x_1^2}{2h_1}+\frac{h_1}{2}$. The properties of the instrument were such that $x_1 = x/\beta$ and $h_1 = h\cos\varphi/\beta$. In the present instrument, $\varphi = 45°$, $\beta = 5$, and $x = 1.78$ mm. Hence,

$$R=\frac{0.45}{h}+\frac{h}{14.1}. \qquad (2)$$

If the sagitta as seen in the eyepiece is precalculated for a number of radii of curvature, then it is possible to determine the radius of curvature of a surface without computing it each time according to (2), simply from the scale readings.

As the radius of curvature increases, the sagitta becomes smaller and the difference between sagittas corresponding to radii of curvature which differ by 0.1 mm also decreases. It follows that as the radius of curvature increases the sagitta must be measured to a higher degree of accuracy if the tolerance remains the same.

The external appearance of the instrument is shown in Fig. 2.

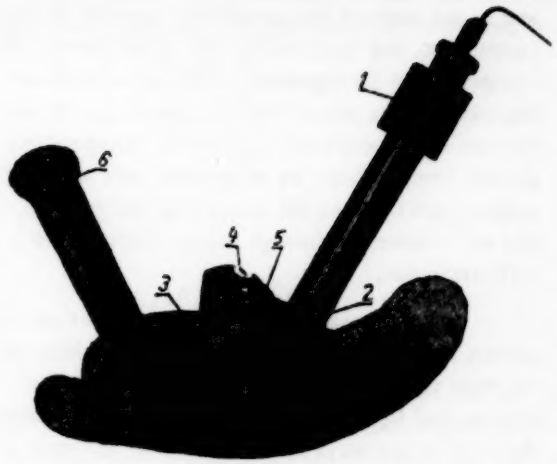


Fig. 2. 1) Illuminating part, including slit; 2) and 3) microobjectives 3.7 × 0.11; 4) aperture for rays of light emerging from the instrument, used to observe the "optical section" of the surface; 5) cylindrical rod on which the specimen is placed so that the controlled surface is directly in front of the aperture 4; 6) eyepiece.

The absolute error in the measured radius of curvature of a detail under control is 0.03-0.05 mm for radii of curvature equal to 0.5-0.8 mm, respectively, and the relative error is 6%.

The experimental error can be made smaller if instead of a plane slit one uses a slit of special three-dimensional form which would give at the surface under investigation a three-dimensional image in the form of an ellipsoidal arc. In this case, the luminous arc visible in the eyepiece will be in focus along its entire length, and so the length of the half-chord, and consequently the sagitta, will be determined to a higher degree of accuracy.

A similar three-dimensional slit when applied in a microscope to a measurement of internal screw threads was found to be satisfactory [2].

In order to facilitate measurements during mass control of details, the eyepiece micrometer may be replaced by a frosted glass screen with scale divisions or tolerance lines drawn on it.

SUMMARY

The present paper describes the construction and principle of a new and original optical instrument based on the optical section principle and designed for the control of objects whose surface radius of curvature is small.

LITERATURE CITED

[1] V. P. Linnik, "An attachment for the measurement of surface displacements along the normal (double microscope)," Trudy GOI, 5, No. 52 (1931).

[2] A. I. Omel'chenko, Stanki i instrument No. 6 (1945).

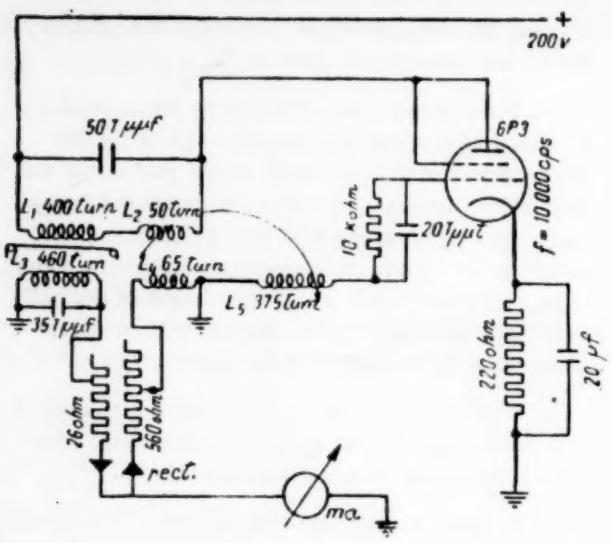
A CONTACTLESS INDUCTION-TYPE ELECTROMICROMETER

N. Ia. Zaslavskaia

At the Institute of Energetics of the Kazakh SSR Academy of Sciences in 1954, a contactless electromicrometer was built for continuous measurement of brass tapes of 50 to 250 μ thickness which are being produced in rolling mills for thin sheet materials. This electromicrometer was installed in December of 1954 on one of the rolling mills for nonferrous materials of the Balkhash plant, and has been in successful operation up to this date.

The principle upon which the operation of the electromicrometer is based consists in the following. The primary winding of an air-core transformer is connected to a high-frequency potential. The metal tape which is to be measured is placed in the air gap between the transformer coils. The magnetic flux from the primary coil induces in the tape eddy currents, which create a magnetic flux that weakens the primary flux. As a result, the emf generated in the secondary coil of the transformer is decreased, and the more, the thicker the tape is.

The circuit of the micrometer (see figure) represents a bridge supplied with electric current by a vacuum



tube audio-frequency oscillator. The coils L_1 and L_3 are parts of the transducer element of the instrument, and the coils L_2 and L_4 are parts of the compensation arrangement. The tape that is being measured is passed through the air gap between the two transducer coils, and in the compensator circuit loop includes an adjustable resistance. The coils L_3 and L_4 form the remaining bridge arms and are connected through cuprox rectifiers to a milliammeter.

The parameters of the bridge circuit are so chosen and adjusted, that for a given thickness of the tape that is measured, the emf's across the coils L_3 and L_4 are equal, and the current through the milliammeter is zero. When the thickness of the tape deviates from the given thickness, the circuit becomes unbalanced, and a current is going through the electrical indicating instrument; from the direction and magnitude of this current, it is possible to judge the character of the thickness change of the tape during the process of rolling. For this purpose the scale of the milliammeter is graduated in microns.

The electromicrometer circuit makes it possible to measure also the absolute thickness of the tape.

The circuit of the instrument is very simple, and it can be assembled from standard components. Structurally the electromicrometer consists of the following parts: the transducer, made up of two brass beakers connected by a rigid bracket; coils L_1 and L_3 mounted in the beakers; the compensating and indicating arrangement, mounted on a chassis and encased in a small box with a panel carrying the milliammeter and the control knobs. The box contains also a voltage stabilizer. The transducer part is mounted directly on the rolling machine, and the box is placed nearby.

Prior to putting the electromicrometer into production service, it was subjected at the plant to industrial application tests, which determined its sensitivity, dependence of the sensitivity upon the thickness, and also the errors connected with vertical vibrations of the tape while traversing the transducer gap during the rolling operation, with differences in the chemical composition of the tapes, with their heating and crystal structure, that is, errors taking place in any micrometer which operates on a strictly electrical principle.

The tests showed that the electromicrometer has high sensitivity, which makes it possible to measure deviations in tape thickness of the order of 1 to 2 μ. The curve representing the sensitivity as a function of the thickness is a nearly straight horizontal line in the entire range of thicknesses (50 to 250 μ), which assures equal precision in measurement of thin as well as of thick tapes.

Sufficiently satisfactory results also were obtained with respect to operational errors of the electromicrometer. Thus, by adjustment of the circuit parameters we succeeded in reducing the error from the vibrations of the tape in the transducer gap to a practically negligible value.

The effect of power-line voltage variations are also practically reduced to zero, thanks to the presence of the anode voltage stabilizer.

The largest differences in the chemical composition of the tapes L62 (0.5% in copper content and 0.003% in iron content) produce an error of 0.3 μ in the measurement of a deviation of 20 μ, and of 1.5 μ in the determination of an absolute tape thickness of 160 μ. Using the electromicrometer as a null instrument, it was also successfully applied in milling of tapes LS59 and L85, and not a single roll was rejected.

Investigation of temperature errors showed that a rise of 10° in the tape temperature produces a shift of about 0.4 μ in the instrument's zero. When it is necessary to take into account temperature effects in measurements of absolute thickness, this can be done by preliminary calibration at various tape temperatures. The sensitivity of the instrument, however, remains constant when the temperature is changed.

As a result of installation of the electromicrometer, the yearly output of one mill was increased by 60 ton and the rejection of end products was decreased in a ratio of 1 to 1.5.

DEVICE FOR THE COMPLETE INSPECTION OF EXTERNAL THREADS

A. P. Khotilin

The device (Fig. 1) is intended for the simultaneous inspection of the effective (mean) diameter (tolerance 0.1 mm) of the rolled 1M16×1.5 d thread of the tractor connecting-rod bolt, and of the amount by which the bolt head face is out of perpendicular to the axis of the effective diameter (0.1 mm on the length of the end face).

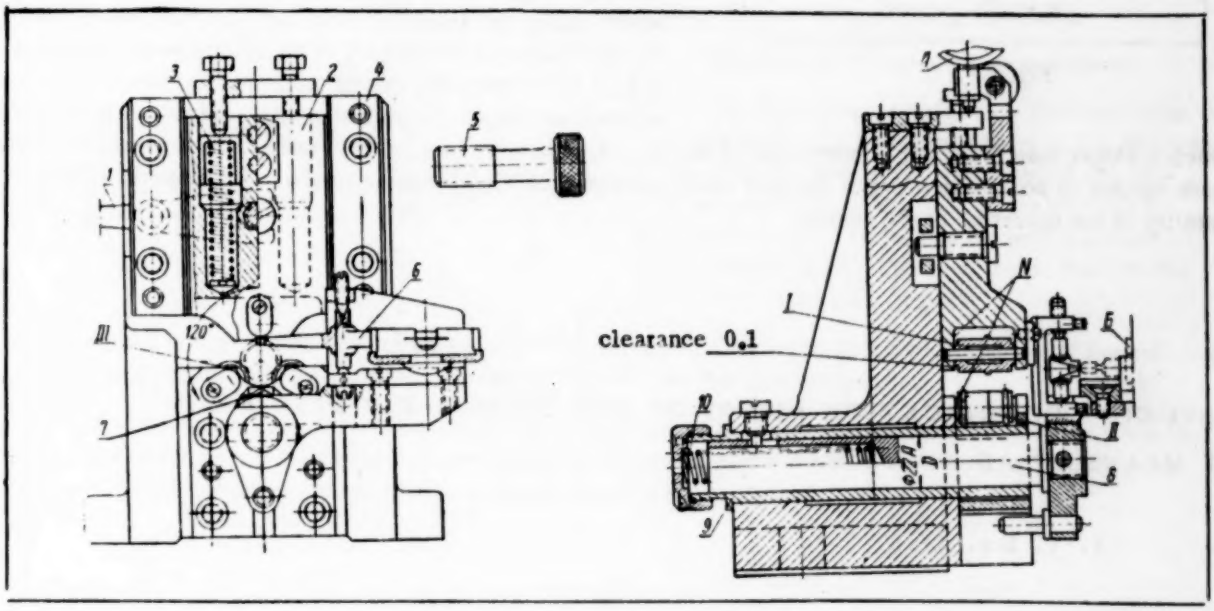


Fig. 1

When the handle 1 is operated, the slide block 2 moves upward along the guides 4 and compresses the spring 3; this opens the gap between the roller I attached to the slide block and the rollers II and III, into which the component being measured is placed.

On lowering the slide block the top roller I produces with the aid of the spring 3 a continuous contact between the component and the lower rollers II and III.

The correctness of the effective diameter of the thread is indicated on the dial A, which is previously set to the reference threads 5 (UPR and UNE).

The slant of the head end face is indicated on another dial B, which is set to the same reference threads. The measuring tip of the dial gauge touches the lever 6, the opposite, pointed, end of which slides on the end face of the bolt head when this is turned, and indicates on the dial the deviations from the perpendicular.

The shaft of the lever 6, the dial gauge B, and the rigid hard-metal stop 7, are mounted on the pin 8.

When the bolt is turned through 180°, the whole of this assembly moves in the sleeve 9 and compresses the spring 10.

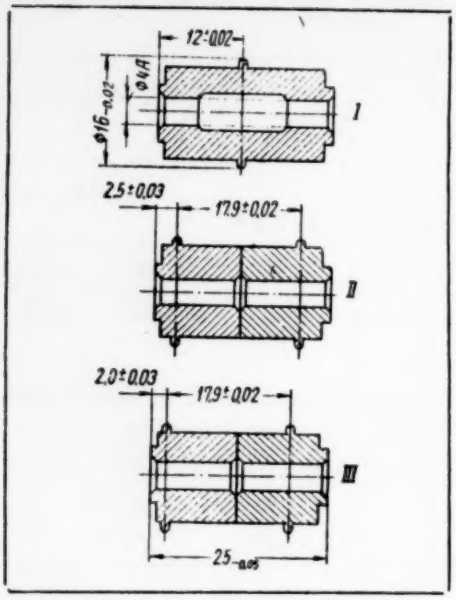


Fig. 2

The main advantage of this device over those used at present lies in the design of the measuring thread rollers, ensuring a high stability of indications, which is of particular importance in the inspection of first- and second-class precision fastening threads.

The measuring rollers I, II, and III are shown in Fig. 2. The roller I has a circular single-thread profile starting at a strictly accurate distance from its left-hand end face, and can be easily rotated about its axis. The rollers II and III consist of two single-thread rollers; each, like roller I, have circular profiles.

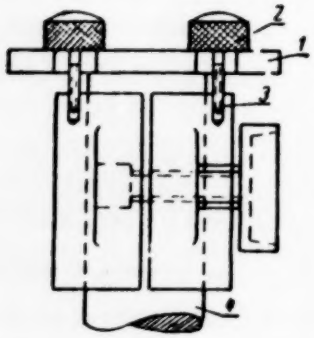
The distance between the circular profile of one pair of rollers (for example, roller II) is chosen in accordance with the length and pitch of the bolt being inspected, and must be considerably smaller than a multiple of the pitch measured on the component being inspected. In the given case the component is placed on threads, the distance between which (along the length) is 12 × 1.5 = 18 mm, while the distance between the threads of the rollers moved together is 17.9 mm; therefore, during the inspection there is always a clearance between a pair of single-lead rollers II (or III) which is larger than the possible pitch error of the thread. The existence of this clearance determines the minimum number of possible settings of the bolt being measured on the measuring rollers, which ensures a high stability in the operation of the device.

CHECKING OF INDICATION ERRORS OF THE OPTICAL DIVIDING HEAD BY MEANS OF AN ANGLE GAUGE

I. T. Dziuman

If a reference disk is not available, then the indication errors of optical dividing heads can be determined by means of a special polyhedron.

In the Voroshilovgrad State Metrology Inspection Laboratory an angle gauge with four working angles of first-class accuracy (measured with an accuracy of ± 5") is used as the polyhedron.



The gauge 1 is fixed by means of two screws 2 to the yoke 3 which has a slit, and is fixed on the end of the cylindrical portion of the mandrel 4, which has a tapered shaft and is placed directly into the hollow spindle of the head. The front part of the yoke has a number of tapped holes arranged in a circle which enable the gauge to be fixed in the required position.

The inspection is carried out in accordance with the method described in the instruction 6-48; owing to the smallness of the angle, it is more convenient to calculate the size of indication errors of the head from the equation

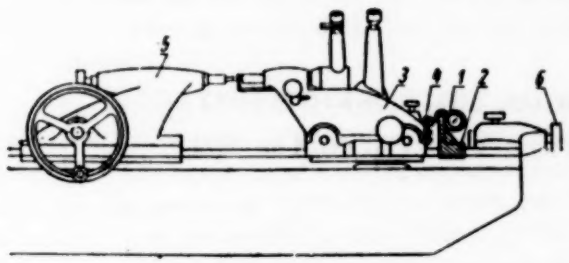
$$\alpha'' = \frac{h \cdot 2 \cdot 10^5}{l} \pm \Delta,$$

where α'' is the deviation in seconds, h is the deviation from parallelism (difference of indications of the optical indicator with respect to the extreme points of the angle gauge), l is the length of the working surface of the angle gauge, $2 \cdot 10^5$ is a constant, and Δ is the correction of the angle gauge.

CHECKING OF MEASURING HEADS OF THE IZM MEASURING MACHINE

N. E. Ermakov

The inspection of measuring heads with one and two μ divisions can be carried out with an adequate accuracy by comparing with the readings on the scale of the optical tube of the measuring machine.



The method of inspection is as follows.

The head 1 being checked is fixed by means of the removable arm 2, which is fixed to the slideway of the machine bed on the right hand of the slide 3. The measuring tip of the head is moved until it touches the lapped surface of the stop 4 secured to the measuring slide. The stop can be fixed to the top of the thermometer casing.

The head is moved into zero position. The scale of the optical measuring tube is also set at the zero position, for which purpose the tailstock 5 is moved until it touches the measuring slide.

During the inspection process the measuring slide is moved by means of the micrometer screw 6 which adjusts the measuring rods of the optical measuring device and of the head being inspected. At the required point the indications of the scales of both measuring devices are compared.

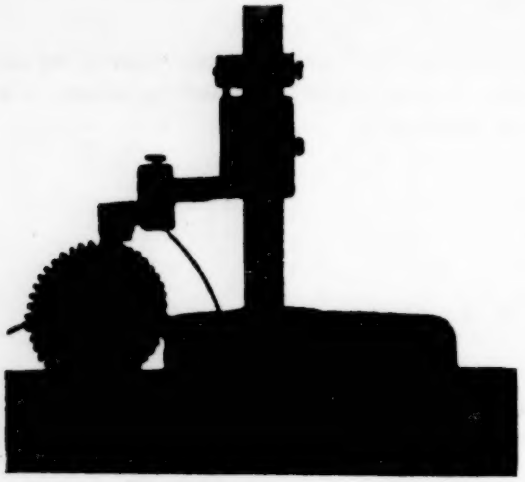
AN ELECTRIC CONTACT ATTACHMENT TO THE HEIGHT GAUGE

I. S. Vasilenko

In measuring the diameters of components with interrupted surfaces and an odd number of projections, the radius is found by measuring the distances from a datum plane to the lowest or highest point of the component's surface, the distance between the plane, and the component's axis being known.

End blocks, dial gauges, or height gauges are used in these measurements.

The first method is time consuming, the second is more efficient, but a measuring arrangement involving a "shock" contact between the workpiece and measuring device affects the accuracy of readings; in addition, in the case of a spherical tip, it is difficult to "catch" the precise moment when the point of the surface is at its "zenith"; the third method, i.e., measuring by means of a height gauge, is the most efficient. In order to increase the sensitivity it is recommended that the height gauge is provided with an electric contact head, which



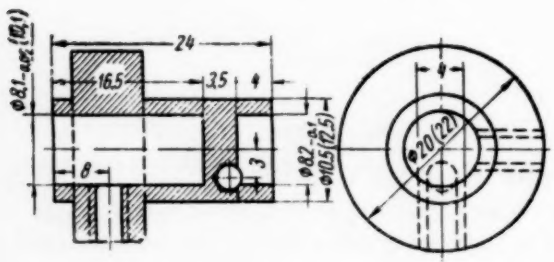
eliminates the error in determining the point of contact between the surface of the component and the measuring tip.

The electric contact head (see figure) consists of a textolite body in which a steel contact piece with a hardened and lapped working surface is screwed. The tail end of this piece is in contact with an electric signal lamp which is screwed into the body, and to the socket of which a short length of flexible wire is soldered; this wire is connected to a transformer or to one of the poles of a torch battery. The other pole is connected to the component. Thus, during the measurements, the moment when contact is produced between a point of the component's surface and the surface of the contact piece is determined not by the touch of the inspector, but by the lighting-up of the electric lamp.

DEVICE FOR CHECKING THE PARALLELISM OF THE WORKING SURFACE OF MICROMETERS WITH A MEASURING RANGE EXCEEDING 100 MM

S. A. Butskii

The following alterations were made when the device for the inspection of the parallelism of micrometers with a range of more than 100 mm [described in Measurement Techniques No. 3 (1957)] was introduced at our works.



The separate guide sleeve was omitted; it was replaced by a collar integral with the end of the main sleeve (see figure); a slit was provided for the ball.

A second set screw was added in the sleeve, since one screw failed to ensure a firm positioning of the sleeve on the setting gauge. The drawing (see figure) shows in brackets the dimensions of sleeves for a 10-mm setting gauge.

MECHANICAL MEASUREMENTS

A NEW INSTRUMENT FOR MEASURING THE ELASTIC MODULUS OF SHEET MATERIALS

S. O. Tsobkallo, G. N. Slavskii and N. A. Chetyrkina

The practical need for the measurement of the elastic characteristics of materials is very great. In the first place, this is of interest in the instrumentation industry, which requires various spring materials, sometimes of the order of a tenth of a millimeter in thickness, for the manufacture of elastic sensing elements (membranes, flat springs, etc.). For the design of these elements it is necessary to have data on the modulus of elasticity of sheet materials and the temperature coefficient of the modulus. These data are also necessary for a new method, worked out by one of the authors [1,2,3], for the measurement of the elastic limit and elastic aftereffects in sheet materials.

The existing methods of measuring the modulus of elasticity can be divided into two groups: static and vibrational (acoustical). While static methods sometimes have a great simplicity, they also have an inherent drawback which is associated with the appearance of direct aftereffect strains in a specimen under static loading. As a straightforward measurement shows, such strains can be a significant part of the total strain under stresses which do not exceed the elastic limit. This effect is especially large for the times involved in measuring the modulus of elasticity at elevated temperatures, and it intrinsically limits the accuracy of all static methods. An additional deficiency of some static methods is that the experiment is impossible to carry out at elevated temperatures.

The vibrational (acoustical) measurement methods are free of the basic deficiencies of the static methods. A method which is suitable for sheet materials has been recently proposed [4]; in this method a specimen in the form of short plate undergoes undamped vibrations at sonic frequencies of about 1000 cps. The specimen is excited by an air flow which is similar to the flow which occurs in reed-type musical instruments. However, measurements of comparatively thin (0.1-0.2 mm thickness) sheet materials are difficult by this method since the required frequencies of about 1000 cps occur at short specimen lengths (less than 10 mm). In addition, as a consequence of the comparatively large ratio of the length to the thickness of the specimen [5], the place of support of the specimen has an effect on the results of the measurements.

We describe below some work of ours which had as its goal the removal of the deficiencies of the above methods; also, we describe a new instrument which measures the modulus of elasticity at elevated temperatures by the bending of comparatively thin (0.1-0.8 mm thickness) and very flexible sheet materials.*

Method of Measurement and Principle of Operation of the Instrument

As a basis, we use the vibrational method of measurement, including a determination of the natural frequency of vibration of a specimen made of the material under investigation. Because of the flexibility of the comparatively thin specimen of sheet material being worked in bending, sonic frequencies (of the order of 1000 cps) can be measured conveniently only with lengths which for practical purposes are unacceptable. Dimensions which are sufficient to guarantee the required measurement accuracy correspond to natural frequencies of vibration which are infrasonic, thus excluding the application of usual high-accuracy acoustical methods of measurement. In the instrument which was developed, low-frequency vibrations are used.

*During the course of the work the authors benefited from the advice of N. N. Davidenkov; during the construction and proving out of the instrument great help was rendered by Z. A. Vashchenko, V. N. Sizov, V. A. Chelnokov, and O. K. Shablinskii.

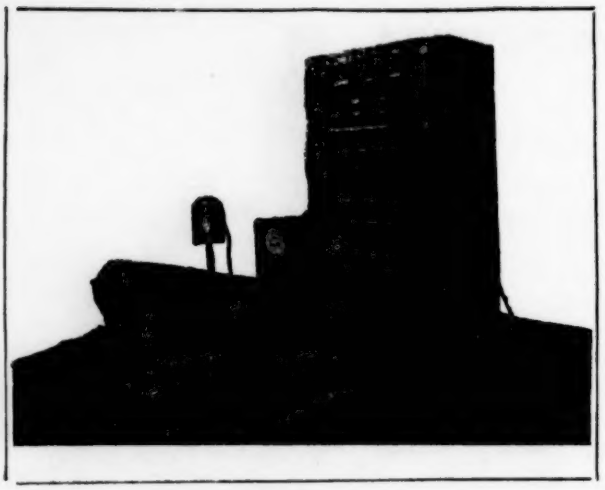


Fig. 1

The specimen in the form of a flexible cantilevered rectangular strip is inserted into an electric furnace and, at the outset of the experiment, is deflected in a horizontal plane; then the specimen is released, whereupon it performs damped oscillations. To convert these to electrical oscillations, we use a photoelectric pickup which has a light source that is directed on the specimen in its middle position. During a complete oscillation, the specimen cuts the light rays twice, giving rise to electrical pulses in the photoelement circuit at double the oscillation frequency of the specimen.

The pulses entering the photoelement control a special electronic device which is designed to measure the oscillation frequency of the specimen accurately. For this purpose, the time necessary for the completion of a specified number of oscillations of the specimen is measured in the device. The result is stored by means of neon tubes and a mechanical counter and can be recorded in the binary system at the finish of the experiment.

The determination of the modulus of elasticity E is based on its known relation to the natural frequency ν of the fundamental mode of a cantilevered specimen:

$$E=3{,}9045\cdot 10^{-9}\frac{\rho l^4}{h^2}\nu^2 \text{ kg/mm}^2 \qquad (1)$$

where ρ is the density of the material of the specimen in g/cm^3, l and h are, respectively, the length and thickness of the specimen in millimeters.

For the measurement of the temperature dependence of the modulus of elasticity,it is necessary to take into account the thermal expansion of the specimen:

$$E_t=E_0\frac{1}{1+\alpha(t-t_0)}\cdot\frac{\nu_t^2}{\nu_0^2}, \qquad (2)$$

where E_0 and E_t are, respectively, the moduli at a normal temperature (t_0) and at an elevated temperature (t), ν_0 and ν_t are the corresponding oscillation frequencies of the specimens, α is the coefficient of linear expansion.

If the temperature is measured at small intervals (as is often the case in the operation of instruments),then one can use a linear dependence of the modulus of elasticity on the temperature; that is,

$$E_t = E_0(1-\eta t), \qquad (3)$$

where η is the temperature coefficient of the modulus.

This quantity is easily determined from vibration measurements by means of the proposed instrument,

$$\eta=\frac{1}{t-t_0}\cdot\left(1-\frac{1}{1+\alpha(t-t_0)}\cdot\frac{\nu_t^2}{\nu_0^2}\right). \qquad (4)$$

Since in (2) and (4) quantities which characterize the geometry of the specimens are absent, the determination of the temperature dependence of the modulus is quite accurate.

Construction of the Instrument

The instrument (Fig. 1) is made in the form of two basic blocks: a block for the excitation of the oscillations of the specimen, and an electronic counter; at the same time, a cathode-ray oscillograph was used.

The block for the excitation of oscillations of the specimen (Fig. 2) consists of a base with various supports, a cantilever, an oven, and a photoelectric pickup.

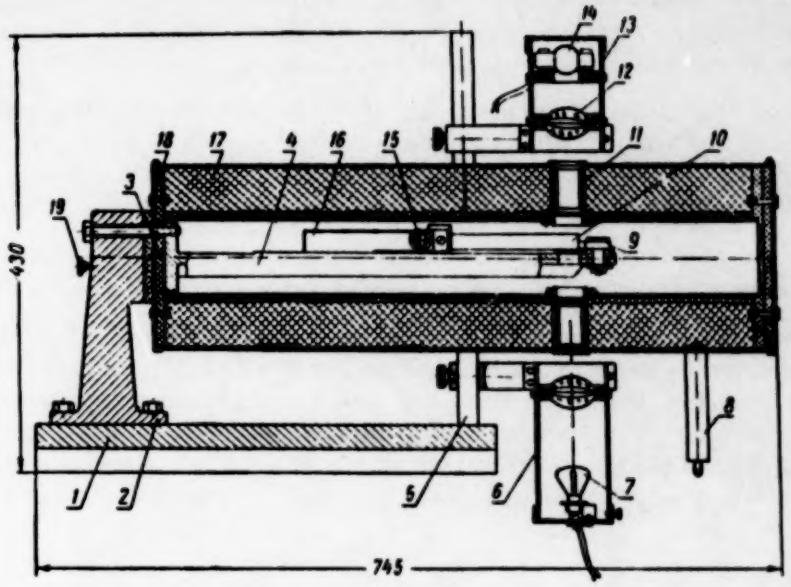


Fig. 2

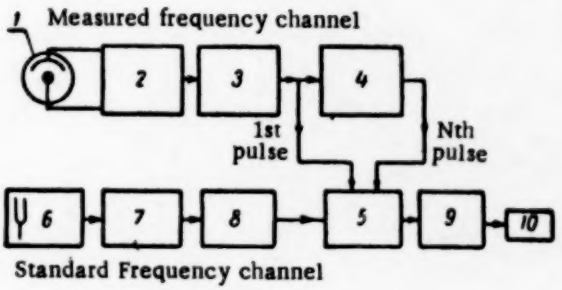


Fig. 3

The horizontal cantilever 4 is attached to the support 2, which rests on base 1, through the thermal insulating lining 3. The cantilever supports adjustable jaws 16 in which, by means of nut 15, the left end of the specimen is supported, the specimen consisting of a strip up to 20 mm in width. The jaws are mounted in such a way that the end of a specimen of arbitrary length will always cut the light rays emanating from the light source chamber 6.

The excitation of oscillations in the specimen is produced externally by means of connecting rod 19, which passes through the rear of the cantilever and rotates cam 9. The cam deflects the specimen sideways until, at a certain angle of rotation of the cam, the specimen is released and begins to perform damped oscillations.

The cantilever, together with the specimen, is inserted into the detachable oven 17, which rests on the support 8 and the lining 3. The oven is detached by means of the ring joint between the linings 3 and 18. To even out the temperatures, the oven has three heating sections along its length. The temperature of the specimen and the uniformity of its heating are controlled by three chromel-alumel thermocouples.

A photoelectric pickup consisting of the light source chamber 6 and the photoelement 13 (attached to support 5) is used to convert the mechanical oscillations of the specimen to electrical oscillations. The light from lamp 7 is focused by a lens through a window in the oven onto the specimen 10; then, the light passes through window 11 and is refocused by lens 12 onto photoelement 14 of type TsG-3.

The electronic counter (Fig. 3) consists of two basic channels, associated with the measured frequency and a standard frequency. In the channel corresponding to the measured frequency, pulses from the photoelectric pickup 1 pass through amplifier 2 and enter an amplitude discriminator 3, which forms pulses of limited amplitude and steep fronts. These pulses either immediately enter electronic relay 5, associated with the channel corresponding to the standard frequency, or they first pass through the scaling circuit 4, which consists of a series of coupled binary counters. At the output of this circuit only every 256th input pulse appears. Hence, relay 5 is acted upon only by the first and 256th of the pulses of the measured frequency. According to the requirement, the factor of 256 can be reduced to 128 (2^7) or 64(2^6).

The channel for the standard frequency has as its main part a sonic tuning-fork-type frequency source 6 with a strictly set frequency of 600 cps, this frequency being attained by the use of a high quality bimetallic tuning form (steel-invar) which has a low temperature coefficient.

The electrical oscillations from the source 6 pass through the amplifier 7 and the limiter 8 and, thus being converted into pulses with a steep leading edge, enter through relay 5 into a second binary scaling circuit 9 having a countdown ratio of 256. At the end of this circuit is attached mechanical counter 10, which records every 256th pulse. The counter operates at a frequency of approximately two pulses per second.

The electronic part of the instrument is equipped with signal lamps which indicate the normal operation of the unit, the beginning and end of the experiment; these can also be used to check out the counting circuit.

If the electronic relay in the channel corresponding to the standard frequency does not close the circuit, the oscillations of the frequency source are counted uninterruptedly. However, the pulses from the pickup 1 control the operation of relay 5. In this, the first pulse opens a path to the scaling circuit 9 for the standard frequency oscillations, and the N-th pulse switches off this circuit. The time T required for N oscillations of the measured frequency ν is equal to n/ν_s, where n is the number of recorded oscillations of the standard frequency ν_s. Hence the measured frequency of oscillation of the specimen is

$$\rho = \frac{P_A(\rho_T - \rho_A)}{P_A - P_T} + \rho_A. \qquad (5)$$

(the factor of $^1/_2$ is introduced because for every oscillation of the specimen there are two pulses sent by the pickup 1).

Method of Measurement

In order to calculate the modulus of elasticity from (1) it is necessary, in addition to the oscillation frequency, to know the density of the material and the thickness and effective length of the specimen.

To determine ρ hydrostatic weighing was used, the specimen being weighed both in air and in toluene on an analytical balance to an accuracy of ± 0.1 mg:

$$\nu = \frac{1}{2}\frac{N}{T} = \frac{1}{2}\frac{Ns_0}{n} = \frac{300N}{n}. \qquad (6)$$

where $\rho_A = 0.0012$ g/cm^3 and ρ_T are, respectively, the density of air and toluene; P_A and P_T are the respective weights of the specimen in these media.

Taking into account the correction for the temperature t of toluene which is determined to an accuracy of ± 0.1°C, we have

$$\rho_T = 0.88412 - 0.92248 \cdot 10^{-3}\, t. \qquad (7)$$

The thickness of the specimen was calculated as the average of 10 measurements, carried out to an accuracy of ± 1 micron.

The effective length of the specimen, that is, the distance from the end of the specimen to the boundary of the jaws of the vise, was determined to an accuracy of ± 0.01 mm.

To measure the frequency of oscillation of the specimen, the number of pulses N to be counted is assigned to the first scaling circuit 4 (Fig. 3). Usually, N is taken equal to 64 or 128. Then, the neon tubes of the second scaling circuit 9 are extinguished by a special cut-off ("break"), resetting the entire apparatus. Next, the specimen is set into oscillation by the triggering mechanism and the instrument automatically starts to operate. At the end of N oscillations of the specimen, the number n oscillations of the standard frequency source is counted off by means of the mechanical counter and the number of neon tubes which are on. With this measurement, which lasts a few seconds, the experiment is finished.

Analysis of Error

Equation (1) is correct for amplitudes of oscillation which are not too large in comparison with the length of the specimen. This circumstance is a consequence of the necessity of viewing the oscillating specimen as a

linear system whose frequency is not amplitude dependent. An analysis of this problem shows that if the amplitude of oscillation exceeds 10% of the effective length of the specimen, it is possible to get systematic nonlinearity errors which are commensurate with the other measurement errors.

Direct observations indicated that the logarithmic decrement of the damped oscillations of the specimen placed in the instrument did not exceed $5 \cdot 10^{-3}$. Such magnitudes of the decrement may give rise to a change in the frequency of less than 10^{-4}%, which is significantly smaller than the random measurement errors in the use of the instrument. Hence, corrections for the damping need not be applied to the results of the measurements.

The necessity of working with comparatively long specimens with a low natural frequency is corroborated in experiments on the effect of the support on the frequency of oscillation [5]. The greater the length of the specimen with respect to its thickness, the smaller is the effect of its deformation in the neighborhood of a support. This is a very important consideration since the length of the specimen enters into (1) according to its fourth power.

The basic accuracy of the measurement of the modulus of elasticity of thin sheet materials is governed by errors in the measurement of the thickness of the specimen, which in practice varies along the specimen's length.

The elastic moduli were measured to relative errors of 0.5-1.0%, depending on the quality of the material and its thickness. The values of E_t/E_0 can be determined with a relative error of less than 1% even under the most unfavorable conditions.

SUMMARY

By the use of a photoelectric pickup and an electronic counting circuit, the instrument which has been described allows one to measure infrasonic damped oscillations with great accuracy. Further, the measurements have been automated.

In order to attain a high accuracy of measurement of the modulus of elasticity, it is necessary that the amplitudes of oscillation of the specimen be as small as possible with respect to its length. This allows one to determine the modulus of elasticity and its temperature coefficient for flexible sheet materials.

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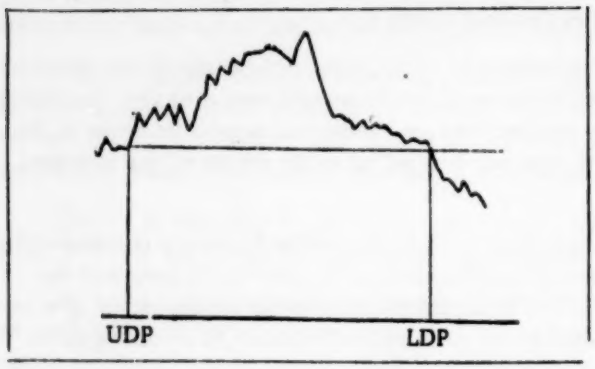
MEASUREMENT OF FRICTION FORCE IN PISTON GROUP OF ENGINE

K. A. Polnitskii

In the V. I. Lenin Kharkov Polytechnical Institute work has been conducted on the measurement of the friction force in the piston group of the IaAZ-204A engine. The friction force was determined in relation to temperature changes, the quality of the lubricating oil, changes in speed of the piston, and the normal force.



The friction force was measured from the liner displacement, which depends on the magnitude of the friction force between the piston and the liner. The liner was held on flexible supports which limited its movement and centered it relative to the cylinder.

When the liner moved it did not come in contact with the cylinder, since its outer radius had been reduced by 1.2 mm by turning on a lathe. The liner supports consisted of a crosspiece fastened with 4 bolts at the bottom, and at the top 4 flexible strips on which the end face of the liner rested and which transmitted the friction force of the piston as it completed a reciprocating movement. The supports were deformed as a result of the movement of the liner.

For the measurement of the mechanical deformations we used a bridge composed of 4 equal-resistance wire gauges cemented on one strip, which was strained as a result of the liner movement. Two gauges were cemented to the upper side of the strip, and the other two on its underside. This arrangement of the gauges increased the sensitivity of the measuring bridge, since on deformation one pair of wire gauges responds to the compression strain, and the other to the expansion strain.

The supply and measuring diagonals of the bridge were connected to a six-filament three-stage amplifier operating from an ac supply.

The results of the measurements were recorded by a nine-loop oscillograph through a voltage stabilizer.

For simulating in experimental conditions the actual conditions of operation of the engine, the water and oil were heated by electric heaters. The temperature of the oil and liner were regulated, where necessary, to the temperature in the engine on a full load at 1100 rpm.

The strips with the cemented wire gauges were calibrated by a milliammeter and oscillograph in the following manner. The engine was cranked without the piston of the test cylinder and with the electric oil and water heaters switched on. After the bridge had been balanced and the scale of forces determined, the supporting strips were loaded successively with weights up to 15-20 kg. When the loading weight was increased, the strips were strained and the unbalance of the bridge increased as a result of the deformation of the strips. Corresponding to each load the milliammeter showed the value of the current on the amplifier output, and on the oscillograph screen we obtained the deflection of the spot of the loop mirror. The value of the current on the amplifier output and the deflection of the spot on the oscillograph with the same load on the strip were not the same and depended on the temperature state of the engine.

A calibration of the strips with the gauges was made at different temperatures of the liner.

The experiments were conducted by cranking the engine with an electric motor at a set number of revolutions in the range 1100-1500 rpm and with the corresponding temperature of oil and liner.

During the movement the following forces act between the liner wall and the piston with rings: a) friction of ring surface on liner wall; b) friction due to displacement of oil layer on sleeve wall by sharp edges of ring; c) friction due to action of normal force; d) friction of piston surface and liner wall across the oil layer separating them.

These forces, as well as the inertia forces of the liner, were recorded on an oscillogram by means of the sensitive element.

The inertia forces of the liner arose in consequence of its uneven motion due to the alteration of the friction force with the angle of rotation of the crankshaft and this affected the deformation of the supports.

The figure depicts an oscillogram showing the variation in the friction force of the piston with rings and the inertia force of the liner with respect to the angle of rotation of the crankshaft at 1100 rpm and oil temperature 80°C for one stroke of the piston.

The zero line was determined on the oscillogram graphically as a straight line parallel to the x axis and intersecting the inclined lines of the process at the dead points. The position of the piston at the upper dead points was marked on the oscillogram by a contact marker.

When the zero line is fixed in this way the friction force at the dead points is equal to zero. This method of determining the zero line can be considered as approximately correct, since the friction force of the piston and rings in traversing the dead points reverses its sign and passes through zero values, if we neglect the inertia force of the liner at the dead points. It was not possible to establish the zero line directly on the oscillograph screen.

The inertia forces of the liner are computed from the formula

$$P_{in} = -m_l j,$$

where m_l is the mass of the liner, collar and cross piece, and j is the acceleration of the liner.

The oscillogram was divided into portions, equal to 10° rotation of the crankshaft, and to 5° close to the dead points, and for each portion we computed the acceleration of the liner from the formula

$$j = \frac{\Delta^2 y}{\Delta t^2},$$

where Δy is the increment of deformation of the strips at each portion during time Δt.

The intervals were marked on the oscillogram by means of timing marks. The scale of movement of the liner was determined in the static state by means of a minimeter. With a load of 5 kg the liner was displaced by 0.0001 cm. The inertia forces of the liner amounted to about 8% of the friction forces of the piston and rings close to the dead points, and over the whole travel of the piston they did not exceed 0.3%. Hence the inertia forces of the liner can be neglected in view of their very small value.

In order that the oscillogram should represent as accurately as possible the variation of friction force between the piston and liner, it is essential that the free vibrations of the liner should have the largest possible frequency in comparison with the frequency of the disturbing force. In our experiment the free vibrations of the liner did not affect the process of tracing the friction force on the oscillogram, since the frequency of vibrations of the liner was 100 times greater than the frequency of the disturbing force at 1500 rpm.

The period of free vibrations was determined from the formula

$$\tau = \frac{2\pi\sqrt{m}}{\sqrt{\kappa}},$$

where $m = \frac{2.2}{981} = 0.00225 \frac{kg \cdot sec^2}{cm}$ is the mass of the liner, collar and crosspiece, and k is the total rigidity of the strips and crosspiece.

The period of free vibrations is

$$\tau = \frac{2 \cdot 3.14 \sqrt{0.00225}}{\sqrt{5000}} = 0.0042 \text{ sec.}$$

The ratio of the periods of the disturbing force at n = 1500 rpm and the free vibrations is

$$\frac{\tau_d}{\tau} = \frac{\frac{60}{1500}}{0.0042} \approx 100.$$

Let us follow on the oscillogram how the friction force changes as the piston moves from the upper dead point to the lower dead point, i.e., during one stroke. At the upper dead points, when the speed of the piston is zero, the friction force is also zero. With increase in speed of the piston the friction force increases. After 20° rotation of the crankshaft the scraper rings pass the scavenge ports of the liner, and as a result of the reduction of surface the friction force diminishes.

After the scraper rings have passed the scavenge ports the friction force again increases with increase in speed of the piston. After 90° turn of the crank, the friction force diminishes with the decrease in speed of the piston, but at about 100° it suddenly increases. The sudden increase of the friction force is depicted on the oscillogram as a peak. Then the friction force rapidly diminishes as a result of the reduction of speed and the passing of the compression rings past the ports. At the lower dead point, when the speed of the piston is zero, the friction force is also zero.

The sharp increase in friction force with reduction in speed of the piston can be explained in the following way. On downward movement of the piston the strips with the gauge also dip downwards. The inertia force of the piston and the friction force in this movement are directed upward and all the clearances present in the pairs, crankshaft – lower bearing, ring – upper bearing, ring – piston are set in a particular direction. At about 80° turn of the crankshaft the speed of the piston has a maximal value and the inertia forces of the piston are zero. After an 80° turn of the crankshaft, the inertia forces change their direction and are directed downward, while the friction force is directed upward. When the inertia forces of the piston exceed the friction force, the clearances in the pairs are set in a different direction. The alternation of the clearances in the pairs during the motion of the piston affected the gauges.

If the oscillogram showing how the friction force varies in relation to the angle of rotation is reconstructed so that it shows the dependence of the friction force on the path travelled by the piston, then the area between the curve of the oscillogram and the zero line will represent the work of these forces during one stroke of the piston, while the mean pressure of mechanical losses of the piston group can be determined from the formula:

$$P_{mech} = \frac{2p_T s \cdot 10^{-4}}{V_n},$$

where $V_n = \pi d^2 s / 4$ is the working volume of the cylinder, m^3; P_T is the mean friction force during two strokes of the piston; s is the stroke of the piston, m; and d is the cylinder diameter, m.

The oscillogram depicts the variation in friction force with respect to the angle of turn of the crankshaft, and permits us to determine the mechanical losses in the piston group and to break down these losses into their separate components.

A SIMPLIFIED APPARATUS FOR STROBOSCOPIC MEASUREMENTS

V. V. Dalin

The simplest stroboscopic instruments in general use employ glow-discharge lamps (neon lamps) which possess serious faults: a) low light flux and unsatisfactory emission spectrum, thus making measurement difficult even with considerable darkening of the stroboscopic disk; b) long duration of light flash when fed by alternating current of industrial frequency, and as a result the stroboscopic star has the form of diffuse segments. This latter effect leads to difficulty in measuring the rotation (slipping) rate S and makes it impossible to measure the angle of error θ.

The universal stroboscopes using high-voltage pulsed lamps, single models of which are being produced at present, have considerable over-all dimensions and their cost is extremely high. In the Moscow Power Institute we have designed an apparatus for stroboscopic measurements, and this apparatus possesses a number of advantages: a) lightness (about 1.5 kg) and small over-all dimensions (20 × 15 × 15 cm); b) high precision and reliability in operation; c) good illumination of the disk or needle; d) safety in operation (the amplitude of the operating voltage is 500 v); e) a simple circuit which can be assembled and put into operation within two or three days; and f) the cost of the components does not exceed 200 rubles

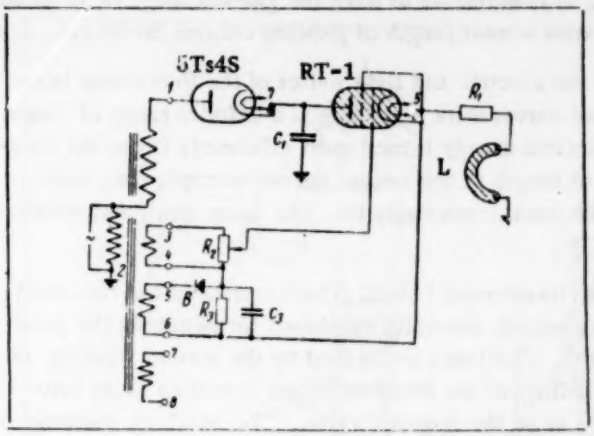


Fig. 1

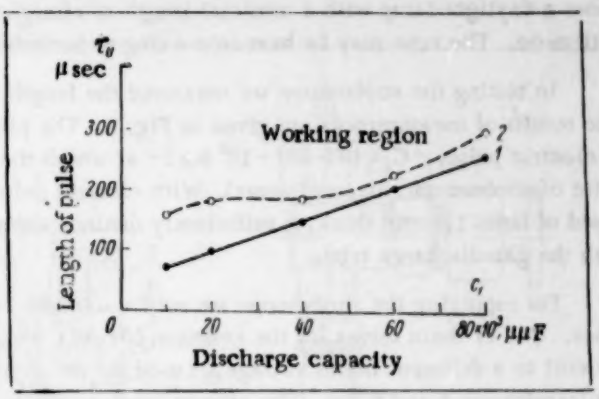


Fig. 2. 1) length of light pulses; 2) length of electrical pulses.

Description of Apparatus

In the apparatus (Fig. 1) a fluorescent lamp or a short gas-discharge tubular sign lamp (L) can be used as the light source. Short pulses of voltage from an electronic generator fall on the lamp 50 times per second.

The capacitor C_1 is charged through the kenotron 5Ts4S at each positive half-period of voltage U_{12} on the terminals of the step-up auto-transformer. At the same time the thyratron RT-1 is locked by a negative bias, which is impressed on the grid from a low-power rectifying device consisting of the supply winding 5-6, one disk of a selenium rectifier B, load resistance R_3, and filtering capacitor C_3.

In the negative half-period of voltage U_{12}, a short controlling pulse, which unlocks the thyratron, is impressed on the grid of the thyratron. The capacitor C_1 is discharged through the fluorescent lamp and ballast resistance R_1, the purpose of which is to limit the discharge current.

The pulses controlling the thyratron can be generated by a peak transformer; good results are also obtained with direct application of the sinusoidal voltage from the winding 3-4. In the latter case, the carbon potentiometer R_2 permits the smooth regulation of the grid voltage, which makes it possible to choose the optimal value of the latter and to obtain accurate operation of the thyratron.

The repetition rate of the electrical and, hence, the light pulses of the apparatus is equal to the mains frequency – 50 cycles.

Test of the Apparatus and Choice of Components

The purpose of the test was to verify the operation of the apparatus and the choice of a number of factors: the type of fluorescent lamp, the duration of the electrical pulse, the maximal amplitude of the current pulse passing through the lamp.

The choice of the nominal power of the standard fluorescent lamp was determined from a consideration of the effective use of the glowing surface of the tube. The apparatus employs a 15 w lamp about 300 mm long. In normal use for illumination the effective value of the anode current of the lamp is about 0.1 amp. In pulsed operation the cathode temperature (one of the incandescent filaments) is equal to the ambient temperature, and this adversely affects the operating conditions of the lamp. Hence the amplitude of the lamp current pulse must not be significantly greater than the normal operating current, i.e., 0.15-0.2 amp. In using a gas-discharge lamp, it is essential that the whole gas volume is uniformly illuminated; a too - small current gives a weak glow. The optimal resistance R_1 is of the order of several kilohms.

The supply voltage U_{12} was chosen to ensure the rapid development of an independent discharge in the lamp: for a fluorescent lamp – about 500 v, for a gas-discharge lamp – 800 v; the lamp current and the supply voltage determined the type of thyratron, TR-0.1/1.3.

Bearing in mind the persistence properties of the phosphor coating on the walls of the lamp envelope, we

chose a daylight lamp with a minimal length of afterglow. It is advisable to have the gas-discharge lamp filled with neon. The tube may be bent into a ring or horseshoe with a total length of glowing column 20-30 cm.

In testing the stroboscope we measured the length of the electric and light pulses of the fluorescent lamp. The results of measurement are given in Fig. 2. The plotted curves show that there is a definite range of lengths of electric pulses – $C_1 = (40\text{-}50) \cdot 10^3$ μμf – at which the electric energy is used most efficiently (from the viewpoint of stroboscopic measurements). With electric pulses of length in this range, the stroboscopic star, composed of lines 1.5 mm thick, is sufficiently distinct when the room is normally lit. The same result was obtained with the gas-discharge tube.

For supplying the stroboscope we used a standard radio transformer ELS-2. The transformer has two octal bases. One of them serves for the kenotron (5Ts4S), and the second, normally employed for switching the primary coil to a different mains voltage, is used for the thyratron. The tubes are heated by the normal windings of the transformer 4 and 6.3 v. The primary and secondary windings of the transformer are linked up as an autotransformer, and this allows the supply voltage to be stepped up to the required value. The auxiliary winding 3-4 for controlling the thyratron is also wound on the core of the transformer; the voltage on its terminals is about 8 v. The transformer casing carries a small panel on which the condensers and resistances are mounted.

The illuminating lamp with reflector is placed up against the stroboscopic disk.

HIGH PRESSURE DYNAMOMETER

V. Ia. Chekhovskoi

In order to study nonstationary processes in systems under high pressure (continuously operating coil boilers, etc.), a membrane-type differential manometer for recording photographically the pressure variations simultaneously from three points,* was constructed at the Bureau of Direct-Flow Boiler Construction. The differential manometer was designed for pressures to 300 atm and was tested at 150 atm.

The construction of the high-pressure membrane differential manometer is shown in Fig. 1. The pressure differential is fed through the connecting pipe 1 and the tube 2 to a cavity, formed between the body 3 and the cap 4. A gasket 5 of annealed copper is used for packing. The cavity is divided into two parts by a metallic membrane 6, which is sealed between two mountings 7 and is fastened to the body by the clamping ring 8 on a thread. A small mirror is fastened to the membrane on a bent leg such that it is opposite the center of the membrane and its plane is parallel to the plane of the membrane. In the cap 4, there is a cylindrical window 9 of organic glass with polished plane-parallel surfaces for passage of a light beam. The seal is provided by compressing a flange of the window between the ring 10 and the cap 4.

In assembled form, the apparatus is filled with a viscous oil (castor) through the nipples 11. At the same time, air is drawn off through the openings which are closed by the needle bolts 12. Having been filled with oil, the apparatus is connected by the connector 13 and packing nut 14 to the impulse tube containing water. Filling the cavity of the apparatus and part of the impulse tubes with oil has two purposes. First, this makes it possible to make the dynamometer from carbon steel instead of stainless; second, it reduces the distortion of the readings of the apparatus.

The middle equalizing valve serves to protect the membrane from accidental rupture and to set the instrument to zero. The bends in the tube 2 at the tee joints 15 are made to prevent air from getting into the cavity of the differential manometer.

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*In the construction of the apparatus, the "membrane with mirror" scheme proposed by N. I. Semenov (ENIN AN SSSR) was used for recording the variations of the pressure differential with atmospheric pressure.

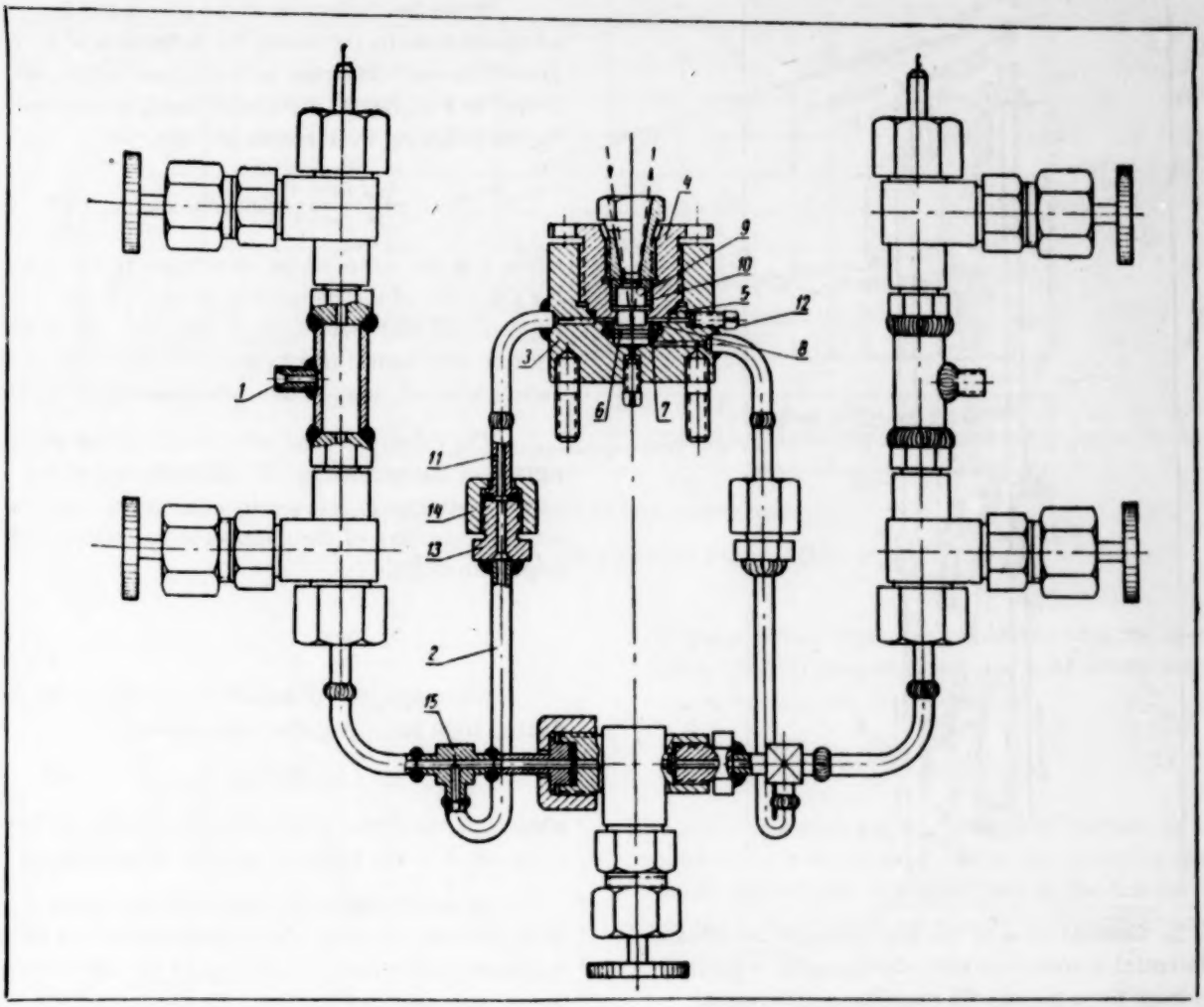

Fig. 1

When a ray from the light source is directed through the window, it is reflected at the mirror, after which it again passes through the window and strikes the scale or the slit of a camera. When the membrane deflects under the influence of a pressure difference, the mirror rotates through a certain angle and the "spot" (reflected ray) moves along the scale or the slit of the camera. The displacement of the spot is registered on the film which moves uniformly behind the camera slit, perpendicular to the direction of displacement of the spot. Uniform motion of the film is accomplished with the help of a constant current motor or a Warren motor with a pinion gear.

The time scale on the photographic film depends on its velocity. Furthermore, in order to read time, impressions of the slit are made on the photographic film by momentarily flashing a light at definite and equal intervals of time. Marks at the beginning and end of the run are made in the same way.

A flashlight bulb with a ~-shaped filament serves as a light source. The filament of the bulb is focused on the scale through a lens of +4 diopters.

In order to simultaneously record the change in the pressure differential from three points, three differential manometers, three light sources, and a camera are mounted on a tubular frame (Fig. 2). The camera and light sources are fastened to the frame with movable swivel clamps, and can be moved along the frame such that the distance between the mirror and the photographic film can change to 1.5 m.

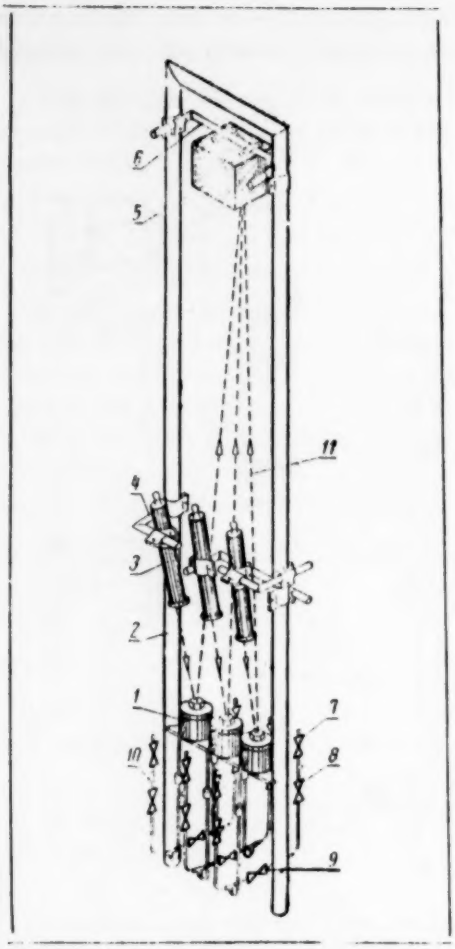

Fig. 2. General view of the high-pressure membrane differential manometer with photographic registration from three points: 1) membrane differential manometer; 2) tubular frame; 3), 4) light source and movable support; 5), 6) camera and movable support; 7) outlet valve; 8) shut-off valve; 9) equalizing valve; 10) inlet for the pressure differential; 11) direction of light ray.

When the deflection of the membrane is comparable to its thickness, the deflection of a plane circular membrane with clamped edges, subjected to a uniformly distributed load, is expressed by the following well-known formula:

$$h_r = \frac{3\Delta p\,(n^2-1)}{16\,En^2 s^3}(a^2-r^2)^2 \text{ cm} \qquad (1)$$

where a is the radius of the membrane in cm, s is the thickness of the membrane in cm, E is the longitudinal elastic modulus in kg /cm^2, Δp is the pressure differential in kg /cm^2, $n = 1/\mu$ (μ is Poisson's ratio), and r is the radial coordinate in cm.

The radius r_0 of the point of inflection of the surface of the membrane, at which the leg of the mirror is clamped, is found by equating to zero the second derivative of the membrane deflection with respect to radius:

$$r_0 = \frac{a}{\sqrt{3}}.$$

The magnitude of the displacement of the reflected light ray along the scale equals:

$$x = L\tan 2\alpha \text{ cm}, \qquad (2)$$

where L is the distance between the mirror and the scale and α is the angle of rotation of the mirror.

For small angles of rotation of the mirror ($\alpha < 4°$), one can make the approximation $\tan 2\alpha \cong 2\tan\alpha$, which leads to an error in the calculation of not more than 0.5%. Since the tangent of the angle of rotation of the mirror equals the derivative of the membrane deflection with respect to radius at $r = r_0$, we have:

$$x \simeq 2L\,\mathrm{tg}\alpha = 2L\left(\frac{dh_r}{dr}\right)_{r=r_0} = \frac{L\Delta p\,(n^2-1)a^3}{\sqrt{3}\,En^2 s^3}. \qquad (3)$$

Figure 3 shows the calibration and calculated curves for different membrane sizes and distances between the mirror and the scale (for the first curve, L = 1485 mm; for the second and third curves, L = 1025 mm). The experimental points have good repeatability with increasing and decreasing pressure differential, in spite of the fact that the membrane was made out of brass. Calibration was carried out at atmospheric pressure by comparing with a liquid (bromoform–water) two-tube differential manometer in parallel with the membrane differential manometer. A repeated calibration at 100 atm agreed with the calibration at 1 atm. The calculated curves were constructed in accordance with (3), in which, for brass, the following values were used: $\mu = 0.35$, $E = 1.1 \cdot 10^6$ kg/cm^2.

Changing membranes, which is provided for by the construction, can change the range of measurement of the pressure differential from 0.1 to several abs. atmospheres. The differential manometer can be used for the measurement of negative differentials of pressure and as a null-instrument.

In the design of the instrument, attention was given to creating conditions in which the differential manometer would give a minimum distortion of the measured pressure differential. This was achieved on the basis of an analysis of the equation of motion for the membrane differential manometer, considering the liquid in the

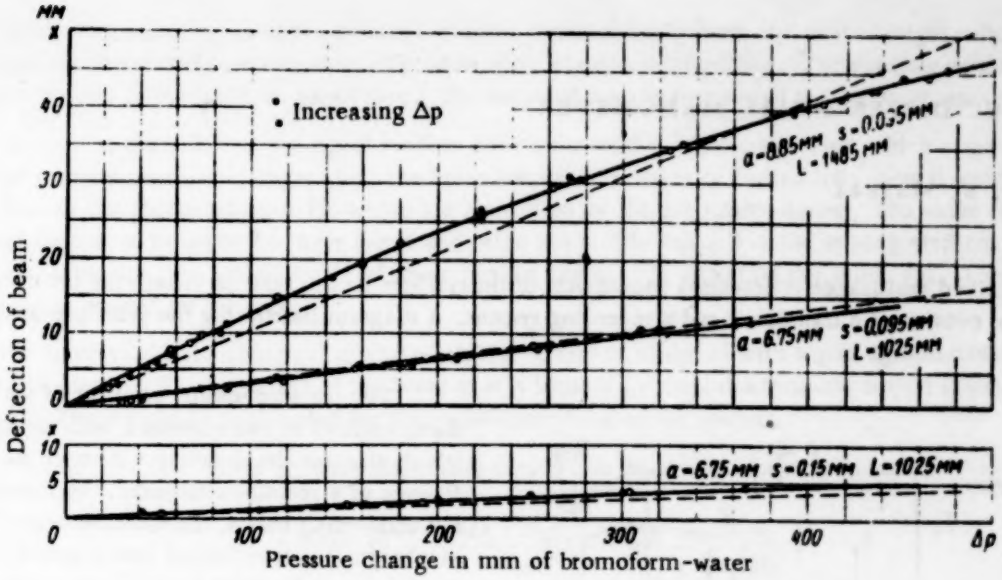

Fig. 3. Calibration data and calculated curves (broken).

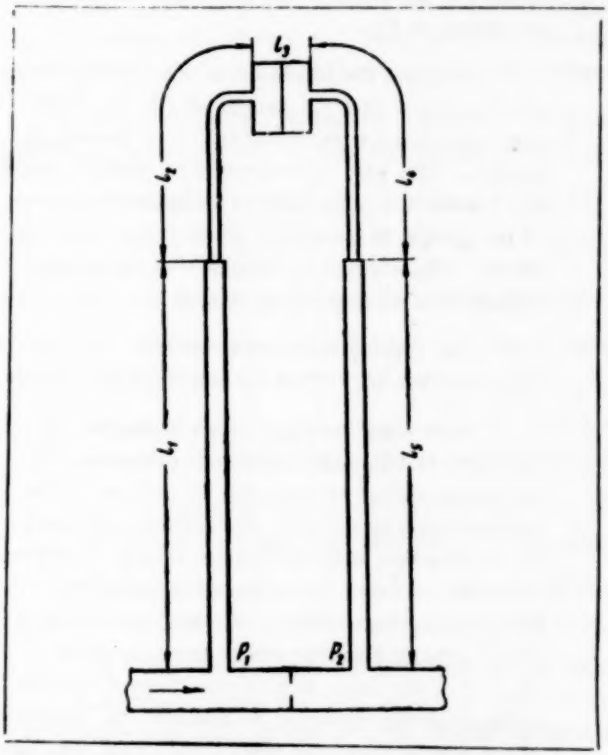

Fig. 4. Diagram for analysis of the membrane differential manometer, with impulse tubes filled with different liquids: l_1 and l_5 filled with water; l_2, l_3, and l_4 filled with castor oil. The portion l_3 with the membrane has radius a.

impulse tubes. Thus, in accordance with the diagram (Fig. 4) one can obtain the well-known differential equation of motion:

$$m\frac{d^2h}{dt^2}+b\frac{dh}{dt}+ch=\Delta p\sin\omega t, \qquad (4)$$

when it is assumed that the force of friction, as a consequence of the small deflections h at the center of the membrane, is proportional to the first power of the velocity, and the pressure differential varies sinusoidally.

The value of the coefficient b in (4) is determined mainly by the lengths of the oil-filled portions of the impulse tubes, while for a constant over-all length of the impulse tubes, the coefficient m changes but little, since the density of water and oil are about the same. Using this circumstance one can, for an assigned over-all length and a given membrane, find analytically the optimum length of the oil-filled portions of the impulse tubes for an allowed small time of damping of the natural oscillations of the instrument, a small phase shift, and a minimum distortion of the amplitude.

Thus, for a differential manometer with a brass membrane (s = 0.2 mm, a = 10 mm, over-all length of the impulse tubes = 5 m and their diameter = 4 mm), it is possible to significantly reduce (almost by a factor of 50) the time of damping of the natural oscillations of the instrument, if the oil-filled portions of the impulse tubes are of length 0.15 m. In this case, with an angular frequency of the measured pressure differential $\omega = 5\ \text{sec}^{-1}$, the phase shift is 3°, and the distortion of the amplitude is practically nonexistent. The angular frequency of the natural oscillations of the instrument thereby remains almost unchanged, and equal to $\omega_0 = 80\ \text{sec}^{-1}$.

MULTIRANGE DIFFERENTIAL MANOMETER

M. B. Maizel'

The described multirange differential manometer of the sylphonelectric type for measuring the difference of two pressures consists of a transducer and a recording system. A diagram illustrating the principle of the transducer is shown in Fig. 1.

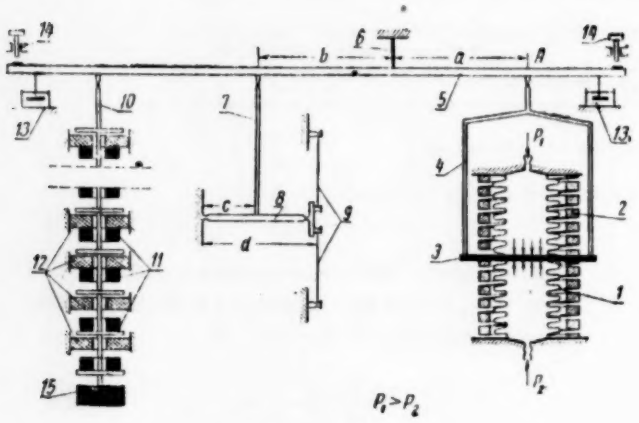

Fig. 1

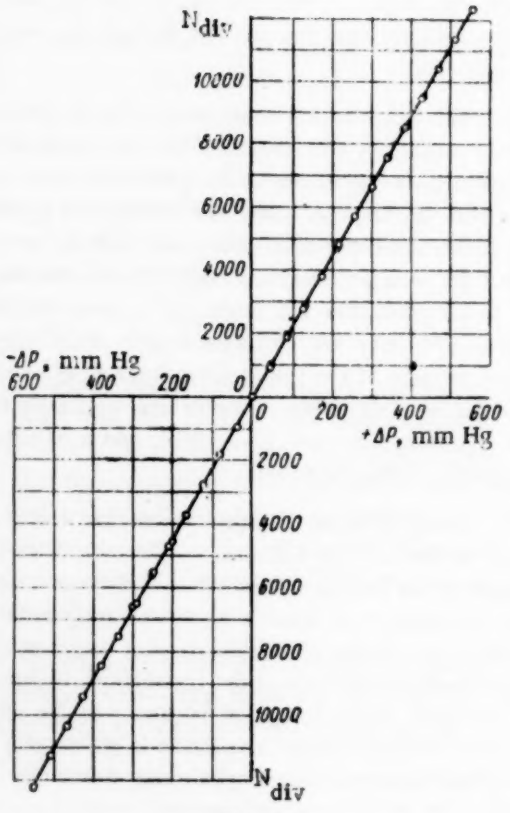

Fig. 2

The pressure sensing element of the transducer consists of two sylphons 1 with springs 2, which displace the diaphragm 3 under the influence of a pressure difference. By virtue of the connecting rods 4, the displacement of the diaphragm 3 is transformed into a rotation of the lever arm 5, which hangs on an elastic hinge 6. The pull rod 7 thereby acts on the elastic beam 8 of the sensing element with wire strain gauges 9, the latter being of a type which are not glued on [1].

Between the insulators of the sensing element are coiled 16 strain gauges of .03 mm diameter constantan wire, connected in 4 measuring bridges. The wire is prestressed in tension. When the elastic beam 8 deflects, the tension of some of the gauges is increased, while it decreases in others. The electrical resistance of the gauges undergoes a corresponding change.

The sensing element is enclosed in a shield to protect the wire from air and thermal currents.

As is well-known, a large hysteresis, attaining 5 to 6%, and a nonlinear characteristic are shortcomings of sylphons. Therefore, in the pressure-sensing element, the sylphons are used in combination with cylindrical springs 2, whose stiffness is several times that of the sylphons themselves. The stiffness of the elastic beam 8 of the sensing element and of the supporting hinge 6 of the lever arm is also many times the stiffness of the sylphons. As a result, the hysteresis of the elastic system is negligibly small, and the displacement of the end of the elastic beam sensing element depends linearly on the pressure change. As a result, the voltage unbalance in the measuring bridges is proportional to the pressure difference acting at the transducer.

An automatic measuring compensator with a three-decade resistance box and a range switch [2] is used as a recording system. The autocompensator can be up to 30 m away from the

transducer. The autocompensator can accommodate simultaneously from one to six bridges, whose measuring diagonals are connected in series across the input of an electronic amplifier. The readings of the autocompensator are printed in numerals on paper tape. The value of a scale division of the autocompensator is $15 \cdot 10^{-6}$ v.

As soon as the value of the signal reaches 1000 units on the autocompensator, which corresponds to one range of measurement, the hanger 10 of the lever arm is automatically loaded by a special weight 11 through the action of the electromagnets 12, which are controlled by the autocompensator. The value of the weight is selected such as to balance the lever arm 5 and bring the elastic beam 8 of the sensing element to the initial position. After this, the second cycle of measurement begins, and after that the third, etc. The number of the range is also printed on the tape.

To improve the metrological qualities, the lever arm is equipped with liquid dampers 13, and all of the hinges are elastic. The excursion of the lever arm is limited by special adjustable stops 14, which serve as arrestors. The weight 15 is intended for the preliminary load of the system.

The sensitivity λ of the pressure measuring device can be predicted from the formula

$$\lambda = 2.67 \cdot 10^{-4} \frac{bd\,(D_i + D_o)^2\, S\, \Sigma(Un)}{caqL\, \Sigma k} \left[\frac{\text{division}}{\text{mm Hg}}\right],$$

where a, b, c, and d are linear dimensions in cm (Fig. 1), D_i and D_o are inner and outer diameters of the sylphons in cm, S is the strain sensitivity of the wire gauges, n is the number of measuring bridges, U is the voltage supplied to the bridges, L is the base of the strain gauges in cm, q is the value of a scale division of the autocompensator, v/division, and Σk is the total stiffness of the pressure transducer (ratio of the load applied to the point A of the lever arm to the vertical displacement of this point), kg/cm.

The sensitivity can change over a wide range due to the number n of measuring bridges connected to the autocompensator, and also due to changes of their supply voltage.

The number of divisions, registered by the autocompensator, is

$$N - N_0 = \lambda \Delta P,$$

where N and N_0 are the present and initial readings, respectively, ΔP is the pressure difference, mm Hg.

The manometer described was calibrated using a two-tube mercury manometer having 1 mm scale divisions and a vernier reading to 0.1 mm.

Figure 2 shows the results of calibration for pressure differentials to ± 600 mm Hg. As can be seen from the graph, the characteristic is linear, and λ = 22.2 divisions per mm Hg.

The mean square deviation in the direction of the N axis, σ_N, of the experimental points from the straight line is 5 to 6 divisions, which consists of ~0.25 mm Hg for the given sensitivity.

The total error is σ_N, which is made up of errors of the gauge and compensator, errors in measuring the quantity ΔP with the two-tube mercury manometer, and other incidental errors.

In order to eliminate errors introduced in measuring the height of the liquid column in the two-tube mercury manometer from the total error σ_N, several series of experiments to determine the characteristic of the ΔP gauge were carried out with the diaphragm of the gauge loaded by weights. From an analysis of the experimental results, it was concluded that the mean square deviation of the experimental points from a straight line is 0.7 to 0.8 divisions of the autocompensator. The maximum error in these experiments attained 2.5 divisions which, with a sensitivity λ = 22.2, corresponded to ~0.1 mm Hg.

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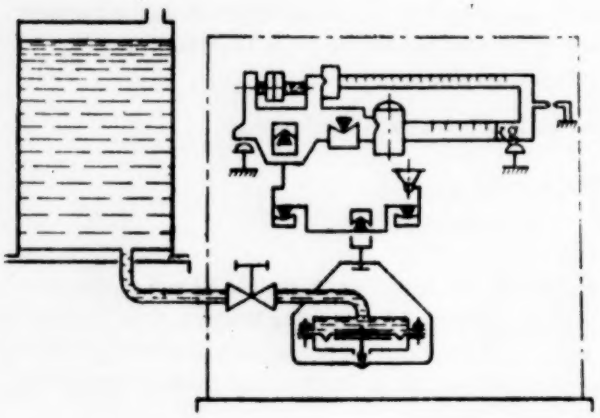
WEIGHT-MEASURING HOPPER FOR LIQUIDS

A. S. Shpigel'glias

In order to determine the weight of liquid products contained in tanks, vats, and other containers, the author developed a manometric weighing apparatus with a membrane pressure vessel (see figure).



The pressure of the column of liquid is received by a pliant, unresisting membrane with a stiff center, and by means of an intermediate weighing arm is transmitted to the weighing beam. The scale of the weighing beam is graduated, for a given container, directly in units of weight. Upon balancing the column of liquid on the membrane by the movable weights, it is possible at any time to determine the amount of liquid in the tubular duct between the level of the bottom of the tank,and the level of the membrane is balanced by the tare weight on the weighing beam.

An experimental check of the precision of the described apparatus was carried out on a working model in which the membrane was prepared from membrane rubberized linen, and medical scales VM-150 served as the weighing beam.

The check was carried out by repeatedly filling a tank with 200 liters of water, using a standard measuring tank II of 10-liter capacity. The error of measurement of the quantity of liquid was 0.3% in the range from 20 to 60 liters, and 0.2% in the range from 60 to 200 liters.

This method is the basis of an automatic weight-measuring hopper. In this measuring hopper there are, besides the elements described earlier, an electromagnetic valve for admitting liquid into the tank, and an electrical contact which connects to the weighing beam after filling the tank with a given amount of liquid. In operation of the measuring hopper, the weights on the weighing beam are set in position for a given weight of liquid. While filling the tank, the beam rests on the support. After filling the tank with the given amount of liquid, the pressure of the liquid on the membrane balances the weight on the beam, and the beam tilts upward, closing the electrical contact, which controls the closing of the electromagnetic valve.

A test of the measuring hopper showed that its error does not exceed 0.3%.

PHOTOELECTRIC TWISTING TORSIONMETER

V. I. Zelenskii

The miniature photoelectric twisting torsionmeter described in this article has an axial distance of 200 mm and is designed to measure Tq (torque) on a shaft revolving at 6000-10,000 rpm.

Two discs (Fig. 1) 4 with narrow radial slits are mounted on two extended half-couplings 1 and 6, one of

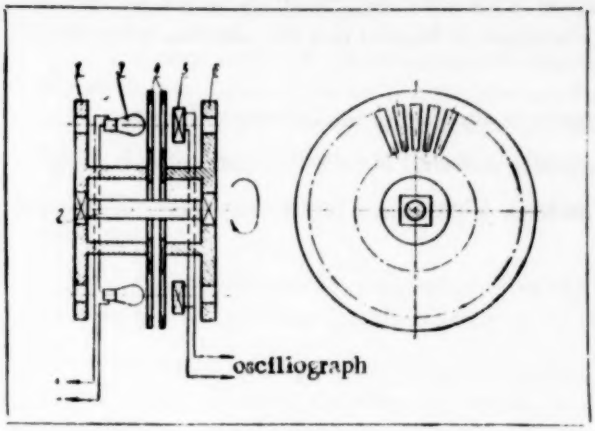


Fig. 1

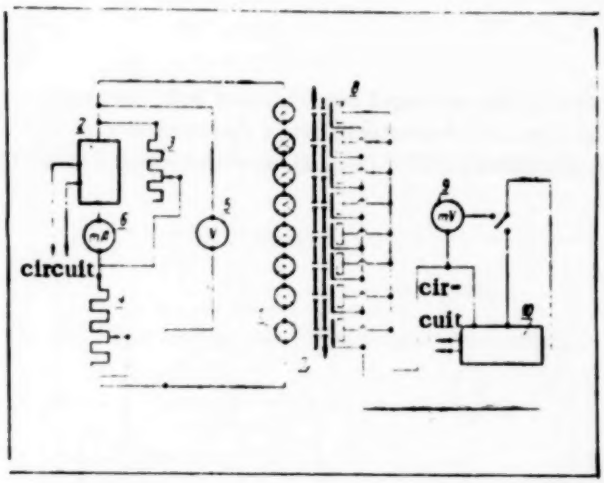


Fig. 2. 1) Illuminating lamps; 2) voltage stabilizer; 3) voltage stabilizer load; 4) variable resistance for regulating the voltage in the lamp circuit; 5) voltmeter for measuring voltage in lamp circuit; 6) milliammeter for measuring load current of voltage stabilizer; 7) discs with slits; 8) photocells; 9) galvanometer for measuring photoelectric current; 10) oscillograph for tape recording.

of which is fixed to the driving and the other to the driven shaft. Each disc has 90 slits. The torque is transmitted through a torsion axle 2 made of 30KhGSA steel fixed to the couplings either by means of a square head or a keyed joint. An aluminum split frame carries on one side 8 automobile lamps 3, and on the other, 8 photoelectric cells type FESS-U3, whose current need not be amplified for operating an oscillograph. The required number of photoelectric cells and electric lamps depends on the desired value of the current and the speed of rotation of the shaft. The light from the lamps falls on the sensitive surface of the photocells. The torsion axle, which transmits the torque, becomes twisted and displaces one disc with respect to the other. The size of the twist depends on the length of the axle, its diameter, and the transmitted torque. The relative displacement of the discs changes the effective gaps in the slits, which in turn vary the luminous flux reaching the photocells which convert it into current. Thus, the value of the photoelectric current becomes proportional to the transmitted torque.

The current was measured on a galvanometer. For recording current values, a loop oscillograph was used.

Figure 2 shows the electrical circuit of the torsionmeter.

The sensitivity of the instrument can be varied within large limits by selecting torsion axles of a suitable length and diameter, changing the size of the slits, the illumination of the photocells, i.e., the power of the lamps and the relative gaps in the discs.

The required diameter and length of the torsion axle are calculated from the usual formulas. Tests have shown that with a rise in the axle diameter the value of Tq at which the relation between it and the current become linear also rises. Moreover, the sensitivity of the instrument decreases at the same time. Hence, the diameter of the axle should be selected as small as possible, without making the twist in the axle exceed the width of a slit.

The tests carried out with the photoelectric torsionmeter showed that it can be used for measuring torque on different shafts and that in comparison with other meters it has the following advantages: simplicity of construction and operation, possibility of visual observation and recording on an oscillograph without amplification, high sensitivity, absence of current-collecting components, and small axial dimensions.

Moreover, the described torsionmeter can measure the torque directly from the working shafts of machines (without inserting the torsion axle) since the relative displacement of discs, i.e., the twisting of the shaft over the length of the instrument base, is measured in minutes, not degrees, as is the case in other torsion instruments.

At the same time, one of its essential defects was also discovered: as the result of the friction of the slit discs against the air inside the tortionmeter during operation, and the proximity of hot bearings of the machines

under test to the body of the instrument, the latter and the photocells heated up rapidly, and this, due to the high sensitivity of the FESS cells to temperature changes, led to errors in measurements (readings decreased with rising temperature). The time of operation of the torsionmeter, therefore, is limited to a few minutes before the heating-up of the photocells.

In order to observe the temperature, a mercury thermometer is attached to the instrument frame.

Tests have shown that the temperature of photocells begins to rise after some 5-7 minutes of operation.

When the torsionmeter is used with shafts rotating at a medium or slow speed (up to 1500 rpm), heating due to air fraction could not be observed in practice.

ELECTROTENSOMETRIC DYNAMOMETER DTB-8

N. F. Cherpnin

In order to measure slowly-changing forces occurring during the prolonged use of anchor bolts fastening layers of rock around mining developments to the main mass, a special electrotensometric dynamometer of the beam type (Fig. 1), operating in conjunction with the electronic indicator EI-1 (Fig. 2), was developed at DonUGI.

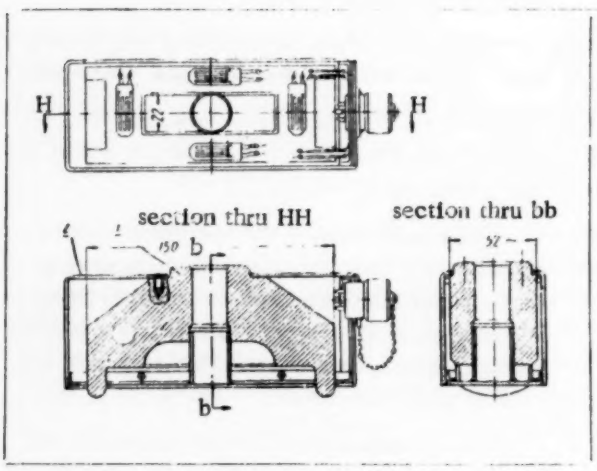


Fig. 1

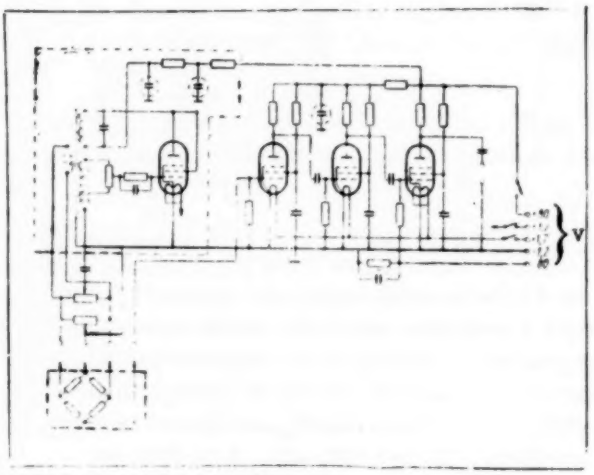


Fig. 2

A doubly-supported beam 1 (see Fig. 1) with a variable moment of inertia was placed in a protective housing 2.

A circular opening for the anchor bolt was made in the middle of the beam. The dynamometer is arranged in the form of a washer under the clamping nut, by which it is pressed to the bearing plate, transmitting the pressure to the rock.

The supporting surfaces of the beam have a double curvature to eliminate torsion during bending.

Four wire strain gauges are glued to the lower part of the dynamometer, in the zone of tension. Hermetic sealing of the gauges is carried out by carbinol paste (carbinol glue with cement) and asphaltic lacquer. The gauges are connected in a bridge circuit. The two working gauges are situated in the middle of the span, and the compensating gauges are rotated by 90° and are glued at the support.

When the nut is drawn down, the lower fibers of the beam are stretched, simultaneously causing a stretching of the wires of the working strain gauges. Therefore, the total ohmic resistance, which is proportional to the relative strain, changes.

A change in the ohmic resistance unbalances the bridge. The voltage unbalance is balanced by a compensating instrument which has a scale graduated in relative units. Balance of the bridge is achieved by listening to an audio signal through headphones. Disappearance of the audio signal indicates that the bridge is balanced and that it is time to take a reading on the scale of the compensator.

The conversion factor from a scale division to the corresponding force is established by calibrating the dynamometer.

A calibration curve is constructed from the calibration data. The curve expresses the linear dependence between the applied load and the reading of the compensator scale.

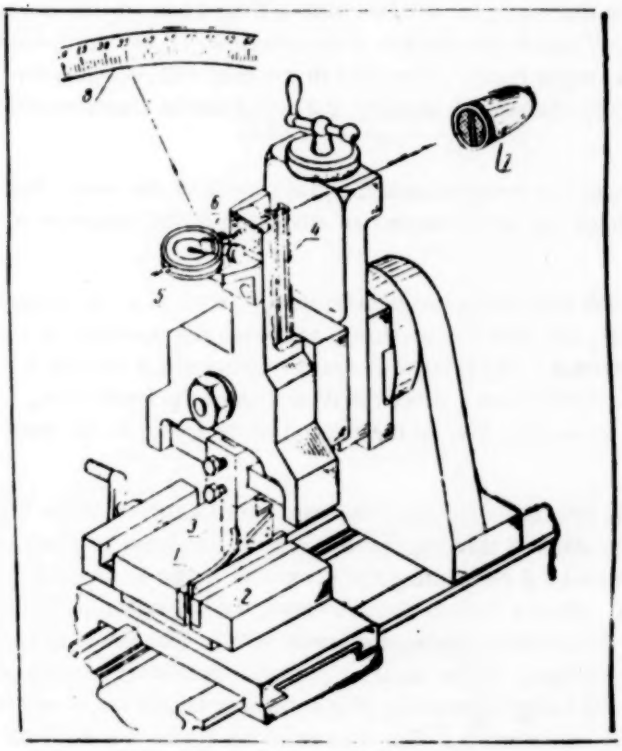
The technical characteristics of the dynamometer follow: range of force measurement – from 100 kg to 8 tons*; value of a scale division – 50 kg; error of the reading from the full value of the load being measured – 1.0 to 1.5%.

During operation it was established that the beam dynamometer functions stably and is convenient to use.

TORSION ARM DYNAMOMETER WITH OPTICAL ARRANGEMENT

V. I. Melamed

Electromagnetic, electrostatic, piezoelectric, and other dynamometers or wire strain gauges glued to the surface of compliant elements are used for measuring forces during the cutting of thin shavings. However, all these arrangements are structurally complicated.



Spring and hydraulic dynamometers are less complicated, but their measuring arrangements register only relatively large displacements of the springy elements of these instruments. This shortcoming rules out the possibility of using mechanical and hydraulic dynamometers of the usual construction for measuring cutting forces while taking light cuts.

Therefore, a torsion arm dynamometer with an optical arrangement, mounted on a lathe, is used in the cutting laboratory ChIMESKh for measuring the horizontal component of the cutting force while planing thin chips. A diagram of the arrangement is shown on the figure.

The workpiece 1 is planed by a wedge-cutter 2, fastened to the holder 3 by two screws. The holder with the wedge is inserted in the socket of a torque arm dynamometer of the ENIMS construction, and is clamped in it by set screws. The displacement of the arm 4 is

*Metric tons.

transmitted to the indicator 5, on whose pointer is fastened a mirror 6. The rotation of the mirror is registered on the scale 8 by the deviation of a ray emanating from the light source 7. Adjustment of the depth of cut is accomplished by a slide whose displacement is registered on a dial, with the value of a division being 0.02 mm. The advancing motion of the workpiece during cutting is accomplished by the carriage.

Because of the deflection of the cutting wedge while cutting, the depth of cut set on the dial of the vertical slide does not correspond to the actual depth of cut. An additional indicator is set up on the machine for measuring the actual depth of cut.

The dynamometer is mounted on a special bracket at a distance of 2 m from the light source and 3 m from the scale. A scale of length 400 cm, placed on the wall, makes it possible to read the cutting force to 125 g.

The dynamometer was tested while planing light cuts of annealed copper. On the basis of the tests carried out, one can assume that the dynamometer described can be used for measuring the cutting forces while taking light cuts.

SERVOMOTOR LEVEL METER AND FLOW DENSIMETER

B. Z. Votlokhin

Figure 1 shows the construction of a level meter for loose or other free-flowing material, an electronic relay circuit (upper right), and a channel for registering the readings of the level meter (lower right).

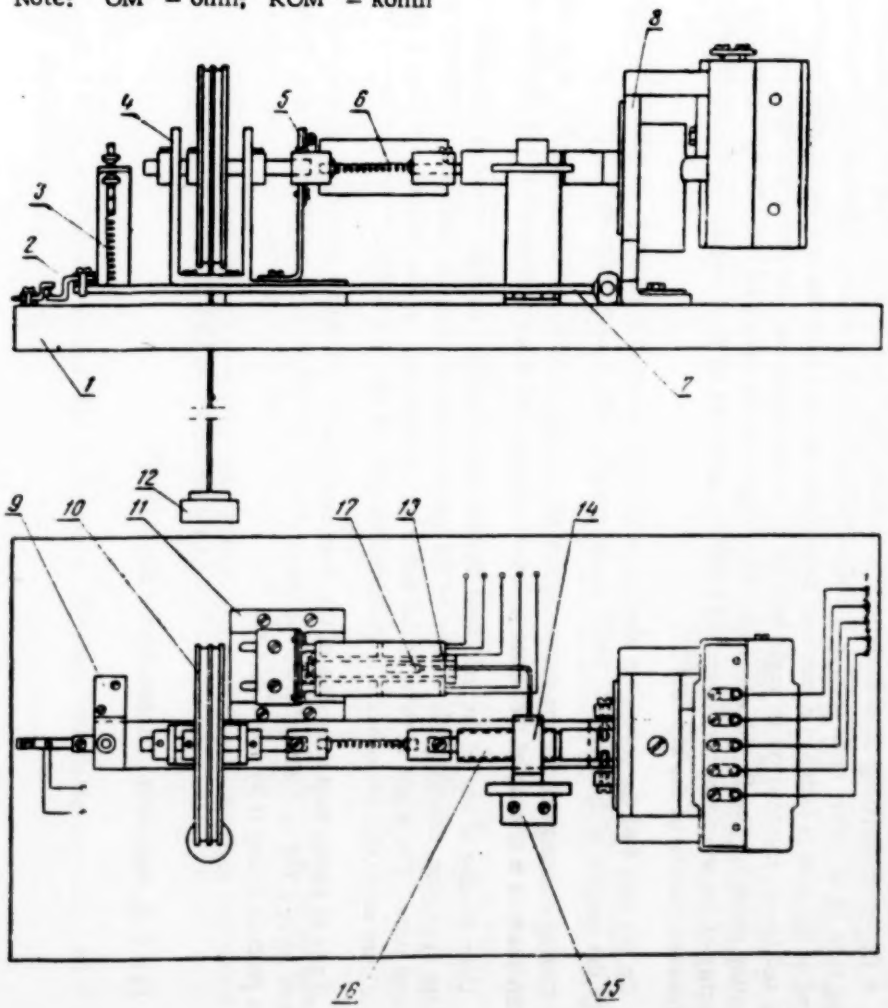
The level meter consists of a reversing electric motor 8, type RD-47, connected through a compliant coupling 6 to a drum 10 which, together with the π-shaped support 4, is fastened to a strip 7. One end of the strip is hinged, and the other end is freely suspended on the spring 3. A cable with a float 12 at its end is wound on the drum 10. A downward displacement of the strip 7 opens the contacts 2 (terminals 6, 7), and an upward displacement closes them. An electronic relay (Fig. 1, upper right), connected to the tube 6P3, controls the rightward and leftward rotation of the electric motor 8 by closing the contacts 2,3 or 1,2 of the electromechanical relay R, type MKU-48.

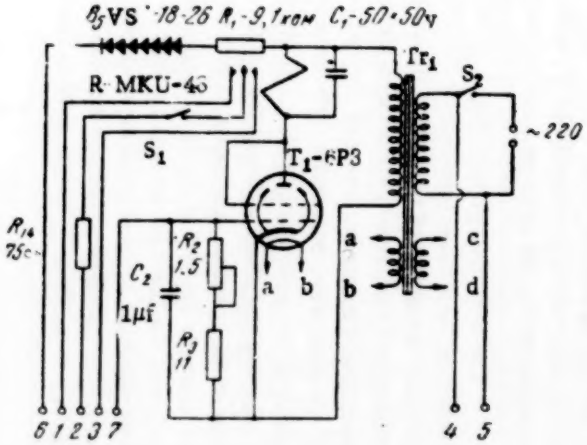
A network $C_2(R_2 + R_3)$ with a definite time constant is connected into the grid circuit of the tube. Normally, with the capacitor C_2 discharged, current flows through the tube, causing an attraction of the armature of the relay R and closing of the contacts 2,3.

Measurement of the level of loose material, liquids with different specific weight, etc., is accomplished in the following manner. Due to the weight of the float, the strip 7 drops down, and since the terminals 6,7 of the pair of contacts 2 are open, capacitor C_2 is disconnected. The relay R closes the contacts 2,3 causing a rightward rotation of the motor and drum, and lowering of the float. After the float attains the level being measured, it touches the surface of the medium being measured. Due to the tension of the spring 3, the strip moves upward and closes the contacts 6,7.

The voltage rectified by the selenium rectifier B_5 (VS-18–26) charges the capacitor C_2 such that the control grid of the tube T_1 goes negative. The tube T_1 cuts off, and stops the anode current; this leads to a release of the armature of the relay R and a closing of the contacts 1,2 connecting the reverse of motor 8, causing a leftward rotation of the drum, and a lifting of the float. After a certain time interval, the capacitor C_2 is discharged through the resistances $(R_2 + R_3)$, and the relay R operates, closing the contacts 2,3. The drum 10 contains a rightward rotation, during which the float begins to drop. There occurs a periodic oscillatory process of probing the interface of the two media, which is the level being measured. The necessary amplitude of oscillation of the float is adjusted by changing the value of the resistance R_2. The tension of the spring 3 is adjusted relative to the weight of the float. Transmission of the readings and automatic registration of the change of

Note: "OM" ≡ ohm; "KOM" ≡ kohm





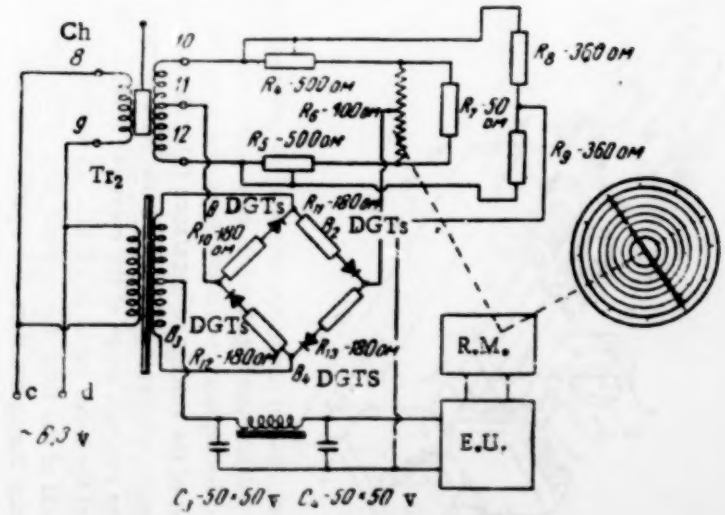


Fig. 1

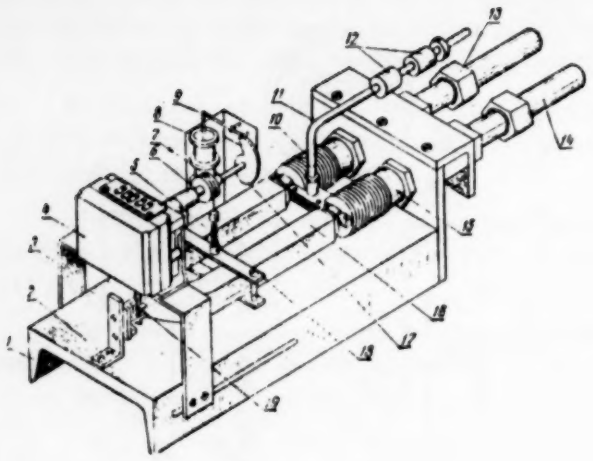


Fig. 2

level is accomplished by employing an induction differential transformer pickup 13, inside which a steel plunger 17 is displaced. The nut and screw 14 and 16, connected with the plunger, transform the rotational motion of the axis of the motor 8 into advancing motion of the nut 14 and the plunger 17. A strip which is movable in the slide 15 is attached to the nut 14 to prevent its rotation.

The induction pickup (Fig. 1, lower right) is connected by a cable (contacts 8-12) with the auxiliary apparatus of type EPD. Balancing of the unbalanced emf from the induction pickup is accomplished by displacement of the sliding contact of the slide wire, connected with the reversible motor of the potentiometer RM. An increase in sensitivity and elimination of the detrimental effect of the reactive component is achieved by phase detection of the voltage of unbalance [1]. The described level meter is applied at the catalyzation plant of the Novo-Grosnypetroleum processing works for automatic registration of the level of the ball catalyst in the flow line. The over-all range of the measured level is 100 cm. The precision of measurement obtained upon calibration of the level meter is ±1 cm. In operation of the level meter, its large advantage appeared – automatic withdrawal of the float during rapid rises of the level. Withdrawal of the float from the layer of loose material takes place during the time of its periodic ascent.

A flow-compensating densimeter with a contact-type transducer is shown schematically in Fig. 2. A bent sensing tube 16 of square cross section is connected by flexible metallic couplings 10 to the inlet line 14. At the end of the tube is fastened a movable contact 19, situated between two immovable insulated contacts – upper and lower, mounted on an angle bracket 2. A reversible electric motor 4 is fastened on a π-shaped supporting stand 3. The liquid whose specific weight is to be measured flows along the sensing tube 16. A balancing of the weight of the measuring system is achieved by displacement of the cylindrical weights 12 along the threaded portion of the bent rod 11.

On the axis 6 of the reversible electric motor 4 is mounted a pulley 7, on which can be wound a cord to change the tension of the spring 5, which is connected to the sensing tube 16.

During a change of the specific weight of the flowing liquid, the initial balance of the sensing tube changes, and this leads to a closing of the upper or lower contacts (decrease or increase of the specific weight).

Upon closing of one of the indicated circuits, the reversible electric motor is connected by means of intermediate apparatus, changing the tension of the spring 5 and bringing the measuring apparatus to the initial balanced state. The angle of twist of the motor axis is registered by the induction pickup 8 and transmitted to an auxiliary apparatus whose scale is graduated in units of specific weight.

Tests of experimental models of the densimeter under laboratory conditions showed that in the general range of from 0.700 to 0.800 g/cm^3, the sensitivity of the system certainly responds to a change in the density of the product filling it by 0.001 g/cm^3.

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ELECTRICAL MEASUREMENTS

COMPENSATED REMOTE MEASURING SYSTEM WITH A STATIC TRANSMITTER

V. S. Popov

Compensated current systems which are widely used for short distance measurements include, as a rule, a dynamic (compensating) element with moving parts [1, 2]. The entire error due to the compensating element is included in the measuring results and the inertia of the element influences the transitional period of the transmitting device.

In the USSR Academy of Sciences Electromechanical Institute,the author has developed a remote measuring system with a static compensating element, designed to measure electrical and nonelectrical quantities: ac power, resistance, ac and dc current, temperature, speed, density and composition of gases, etc. [3]. The absence of moving parts considerably increases the lifetime and reliability of the system.

The remote measuring system consists of a bridge with an indirectly heated resistance connected in one of its arms (Fig. 1). The bridge is fed from an auxiliary source of ac of industrial or higher frequency. A line is connected to the bridge output through phase sensitive rectifier, and filter LC which smoothes out the pulsating current. The negative feedback which automatically balances the bridge is achieved by connecting the heater of the resistance to the output line.

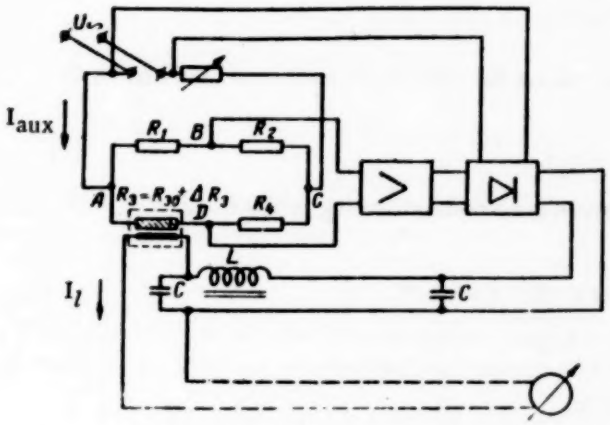

Fig. 1

When the measured quantity varies,it affects one or more arms of the bridge and throws it out of balance. The arms'resistances are chosen in such a way that automatic balance is attained by means of the heating current for the whole range of the measured quantity changes. The system is obviously rather sluggish. With an appropriate choiceof parameters, however, it is possible to make the sluggishness sufficiently small.

Let us determine the relationship between the line current I_l and the measured quantity which can be expressed in terms of the gain of the system.

In order to determine the gain of the system on open circuit,it is necessary to multiply together the absolute values of the static stage transfer factors.*

1. Bridge

Let us examine the case when the heating due to the current flowing through the sensitive part of the heating resistor is negligibly small.

*A static stage transfer factor we shall understand to be the partial derivative of the output quantity of the stage with respect to its input quantity at a stable state.

Considering that the input resistance of the amplifier is considerably larger than the bridge arms' resistances, the relationship between the voltage across the measuring diagonal of the bridge U_d and the auxiliary current feeding the bridge I_{aux} will be:

$$U_d = I_{aux} \frac{R_1 R_4 - R_2 R_3}{R_1 + R_2 + R_3 + R_4}, \quad (1)$$

where R_3 is the resistance-sensing element of the heated resistor, which in this case equals the resistance of the bridge arm AD.

An additional line resistance is connected in series with the bridge to ensure a constant auxiliary current which feeds the bridge independent of the changes in the bridge arms during measurement.

Considering that the bridge is always close to balance, i.e.,

$$R_1 R_4 \simeq R_2 R_3,$$

we obtain

$$K_1 = \frac{d\ U_d}{d\ R_3} = \frac{-R_2 (R_1 + R_2 + R_3 + R_4) - (R_1 R_4 - R_2 R_3)}{(R_1 + R_2 + R_3 + R_4)^2} \simeq$$

$$\simeq -\frac{R_2}{R_1 + R_2 + R_3 + R_4}.$$

2. Electronic Amplifier

From Fig. 1 it follows that the line current I_l is proportional to the voltage at the amplifier input U_d, and to the gain of the amplifier, but inversely proportional to the output impedance z_o, hence:

$$I_l = \frac{U_\partial\ \kappa_u}{z_o}. \quad (2)$$

Whence

$$K_2 = \frac{d\ I_l}{d\ U_d} = \frac{\kappa_u}{z_o}.$$

3. Heated Resistor

The transfer coefficient of the heated resistance depends on the type of the resistance used and on the current flowing in the heater (line current) I_l

$$R_3 = R_{30} + F(I_l), \quad (3)$$

where R_{30} is the resistance of the sensitive element when there is no current flowing in the line.

Hence,

$$K_3 = \frac{d\ R_3}{d\ I_l} = \frac{d\ F\ (I_l)}{d\ I_l}.$$

Thus the gain of the system on open circuit is equal to:

$$K = K_1\ K_2\ K_3 = \frac{\kappa_u R_2\ I_{aux}}{(R_1 + R_2 + R_3 + R_4)\ z_o} \cdot \frac{d\ F\ (I_l)}{d\ I_l}. \quad (4)$$

With the knowledge of the system gain, it is possible to determine the required value of the relation between the line current and the measured quantity.

From (1) and (2) we have

$$R_1 R_4 - R_2 R_3 = \frac{I_l z_o}{I_{aux} \kappa_u} (R_1 + R_2 + R_3 + R_4).$$

After taking (3) and (4) into account we obtain:

$$R_1 R_4 - R_2 [R_{30} + F(I_l)] = -\frac{I_l R_2}{K} \cdot \frac{d\ F\ (I_l)}{d\ I_l}.$$

Hence

$$F(I_l)+\frac{I_l}{K}\cdot\frac{d\,F(I_l)}{d\,I_l}=\frac{R_1\,R_4-R_2\,R_{30}}{R_2}. \qquad (5)$$

It follows from this expression that with a constant gain, the line current will be the function of quantity $\frac{R_1R_4-R_2R_{30}}{R_2}$ which, in a general case, can be regarded as the measured quantity $A_x=\frac{R_1R_4}{R_2}-R_{30}$.

At $R_4=R_2=$ const and $R_{30}=$ const, the line current is a function of the active resistance R_1. It should be noted that resistance R_1 can represent a sum of resistances $R_1^1+R_1^n+\ldots+R_1^n$, i.e., in this case the line current will be the function of a sum of active resistances. At $R_4=R_2=$ const, the line current will be the function of the difference of resistances R_1-R_{30}. At $R_2=$ const and $R_{30}=$ const, the line current will be the function of the product of two active resistances R_1R_4. At $R_1=$ const $>>\frac{R_2R_{30}}{R_4}$ and $R_{30}=$ const, the line current will be the function of the quotient of two active resistances R_4/R_2.

Thus, a system with a static transmitter can be used for remote measuring of a difference, sum, product and quotient of active resistances. In addition to this, the system is designed to measure, at a distance, dc and ac current, temperature, speed, density, and composition of gases and other quantities which in one way or another can change the values of active resistances. The system can also be used for remote measuring of ac power, which by means of a transducer with heated resistances, a bolometric power transducer, can control the difference between two sensitive resistances.*

It follows from (5) that the relationship between the measured quantity and the line current is represented by a function of the type $F(I_l)$, i.e., by the characteristic of the heated resistor. The required relation can be linear if the sensitive resistance has a linear relation to the heating current.

$$R_3=R_{30}+c\,I_l\,,$$

i.e.,

$$F(I_l)=c\,I_l\,.$$

In this case (5) will take the form:

$$c\,I_l\,(1+\frac{1}{K})=\frac{R_1\,R_4-R_2\,R_{30}}{R_2}=A_x.$$

In a more general case when the ohm-ampere characteristic of the heated resistor can be approximated to a step function of the form

$$R_3=R_{30}+\Delta R_3=R_{30}+c\,I_l^{\alpha}\,,\ \text{where}\ \alpha=\text{const},$$

a linear relationship between the measured quantity and the reading of the receiving instrument can be obtained by means of an auxiliary heating resistor connected to the line on the receiving side.

It should be noted that the effective temperature coefficient of the heated resistor can be decreased by shunting the heater with a linear resistor. The values of the nonlinearity indicator α in a series of resistors of the IEM type were found to be between $\alpha=1.72$ and 1.73, i.e., for the first approximation they can be considered equal.

Assuming the characteristics of the heated resistors at the transmitting and receiving ends to be identical, the change in the resistance at the receiving end will be

$$\Delta R=\Delta R_3=F(I_l)=c\,I_l^{\alpha}.$$

and hence

$$F(I_l)+\frac{I_l}{K}\cdot\frac{d\,F(I_l)}{d\,I_l}=\Delta R+\frac{I_l}{K}\cdot\frac{d\,(c\,I_l^{\alpha})}{d\,I_l}=$$

$$=\Delta R\,(1+\frac{\alpha}{K}).$$

* Such a power transducer was first developed in the VEI [1] and later considerably improved in the USSR Academy of Sciences Electromechanical Institute.

Taking (5) into consideration, we obtain

$$\Delta R = \frac{1}{1+\frac{\alpha}{K}} \cdot \frac{R_1 R_4 - R_2 R_{30}}{R_2}. \qquad (6)$$

The resistance of the sensitive element of the auxiliary heated resistor at the receiving end can be measured by connecting the resistor as an arm of an automatically balancing bridge (Fig. 2). With a suitable choice of bridge arms, the readings become directly proportional to the measured value.

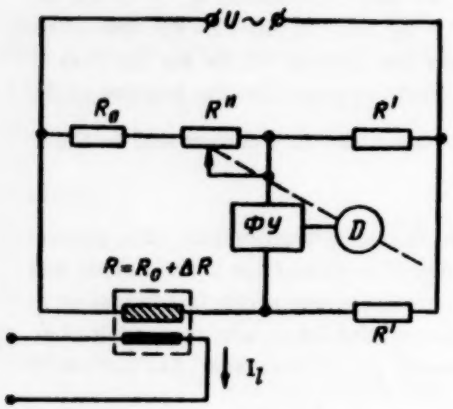

Fig. 2

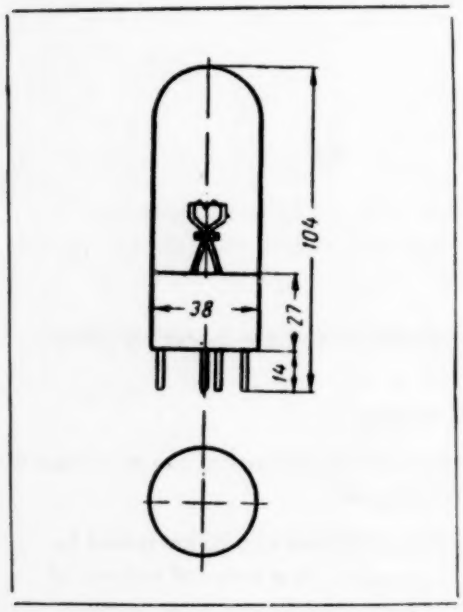

Fig. 3

For a stable operation of the remote measuring system a phase-sensitive rectifier must be used. Otherwise, when there is a sudden change in the measured value the phase of the voltage at the diagonal of the bridge can vary by 180°. At the same time, the negative feedback will become positive and false readings will result.

For summing the readings at the transmitting end, it is only necessary to connect the objects of measurement in series with each other into one of the arms of the bridge, producing a summation of resistances, or into two adjacent arms of the bridge, producing a sum of resistance differences (the case of remote measurement of power). For summing readings at the receiving end, it is necessary to connect the heating elements of the resistors to each line and the sensitive elements in series with each other into an arm of an automatic bridge. Since the variation of the resistance of each sensitive element is proportional to the measured quantity (6), the readings of the automatic bridge will be directly proportional to the sum of the measured quantities.

As a compensating element for this system, it is possible to use a heated resistor with a metallic or semiconductor sensitive element.

The heated resistors with a metallic sensitive element usually have a nichrome heater and a sensitive element made of platinum, tungsten or nickel. Heated resistors developed in the USSR Academy of Sciences Electrical-Mechanical Institute consist of a tungsten spiral surrounding a glass tube with a nichrome heater inside it. The heater and the spiral are enclosed in an air-filled glass bulb which serves to protect the heated resistor from any mechanical damage (Fig. 3). The table gives some of the constructional and technical data of the above heated resistors.

Experimentally confirmed calculations have shown that the relation between the spiral resistance and heating current has the form:

$$R_{cn} = R_0 + c\, I^{\alpha},$$

where R_0 is the initial resistance of the spiral, $\alpha \simeq 1.7 = \text{const}$, and c is a constant depending on the constructional data of the heated resistor.

The above equation holds at the excess temperatures of the spiral of 20-25° to 230-250°C. The maximum working temperature was fixed at 200°C. According to calculations the resistance of the tungsten spiral will increase due to oxidation at this temperature in 4000-5000 hours by 0.1%.

Description	Value
Diameter of heater	20 μ
External diameter of insulating tube	40 μ
Thickness of insulating tube	8 μ
Diameter of spiral filament	12 μ
Internal diameter of spiral	60 μ
Time constant	0.13 sec
Sensitivity (for a spiral pitch of m = 50μ and length l = 6 mm)	0.01 ohm per ma[1.7]

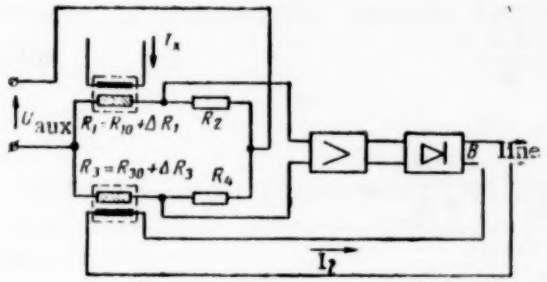

Fig. 4

The stability of the ohm-ampere characteristic of the heated resistor was investigated experimentally during 18 months. The sample had worked under varying conditions for some 500 hours in this period. Over the whole period the change in the characteristic of the resistor did not exceed 0.2%; the error of measurement was of the same order.

Heated resistors with a semiconductor sensitive element are very sluggish (some 40 sec operation time) and are less stable than the metal resistors. Hence, the possibilities of using thermistors in the system are limited.

When a metal heated resistor is used in a remote measuring system and the resistor characteristic is $F(I_l) = c\, I_l^{\alpha}$ the relation between the line current and the measured quantity according to (5) will be

$$I_l = \left[\frac{R_1 R_4 - R_2 R_{30}}{c R_2 \left(1 + \frac{\alpha}{K}\right)}\right]^{\frac{1}{\alpha}} = \left[\frac{A_x}{c\left(1 + \frac{\alpha}{K}\right)}\right]^{\frac{1}{\alpha}}. \qquad (7)$$

A remote measuring system with metal heated resistors possesses an interesting property, viz., it is possible to obtain between the measured quantity and the line current a linear relationship if the measured quantity is the current of voltage controlling one of the bridge resistances by means of an auxiliary heating resistance (Fig. 4).

Let the characteristic of one of the heated resistors have the form $R_1 = R_{10} + cI^{\alpha}$ and of the other $R_3 = R_{30} + cI^{\alpha}$. According to (7), we have

$$I_l = \left[\frac{R_4 (R_{10} + c_1 I_x^{\alpha}) - R_2 R_{30}}{c R_2 \left(1 + \frac{\alpha}{K}\right)}\right]^{\frac{1}{\alpha}}.$$

By selecting bridge arms to fulfill the following condition

$$\frac{R_4}{R_2} = \frac{R_{30}}{R_{10}},$$

we obtain

$$I_l = \left[\frac{c_1 R_4}{c R_2 \left(1 + \frac{\alpha}{K}\right)}\right]^{\frac{1}{\alpha}} \cdot I_x,$$

i.e., the line current is directly proportional to the measured quantity.*

The sensitive element of the heated resistor responds to the changes in the heating current after a lapse of time τ = 0.007-0.009 sec, not instantaneously. This retardation is caused by the fact that the filament and the

*A similar circuit was proposed independently of us by E. M. Kutiasheva for checking faults.

spiral are separated in space. Experimental investigations have shown that this retardation causes oscillations with a system gain of the order of 30-35 or more. This results in small vibration of the receiving instrument pointer. The system is stable at K = 25-30, i.e., with a feedback coefficient of the order of 0.035.

The critical value of gain can be raised by increasing substantially the value of the filter condenser.

Let us examine the influence of external factors on the accuracy of the system. The relative change of the line current caused by changes in the gain of the system can be determined by differentiating (7)

$$I_l^{-1}\, d\, I_l = \frac{R_1 R_4 - R_2 R_{30}}{c\, R_2} \cdot \frac{d\, K}{\left(1+\frac{\alpha}{K}\right)^2 K^2}.$$

By dividing the above expression by (7) we obtain

$$\frac{d\, I_l}{I_l} = \frac{1}{K+\alpha} \cdot \frac{d\, K}{K}. \tag{8}$$

According to (4) the gain is equal to

$$K = \frac{\kappa_u R_2 I_{aux}}{(R_1+R_2+R_3+R_4)\, z_o} \cdot \frac{d\, F(Il)}{d\, I_l} = \tag{9}$$

$$= \frac{\alpha\, c\, \kappa_u R_2 I_{aux} I_l^{\alpha-1}}{(R_1+R_2+R_3+R_4)\, z_o}.$$

Assuming quantities α, c and the resistance of the bridge arms to be constant, as the result of taking the log and differentiating (9), we obtain

$$\frac{d\, K}{K} = \frac{d\, \kappa_u}{\kappa_u} + \frac{d\, I_{aux}}{I_{aux}} + (\alpha-1) \cdot \frac{d\, I_l}{I_l} - \frac{d\, z_o}{z_o}.$$

Taking (8) into consideration we have

$$\frac{d\, I_l}{I_l} = \frac{1}{K+1} \cdot \left(\frac{d\, \kappa_u}{\kappa_u} + \frac{d\, I_{aux}}{I_{aux}} - \frac{d\, z_o}{z_o} \right).$$

The relationship between the relative change in the value of the measured quantity A_X and the relative change in the line current I_l can be determined by differentiating A_X with respect to I_l [see (7)]:

$$\frac{d\, A_x}{A_x} = \frac{d\left(R_1 \frac{R_4}{R_2} - R_{30} \right)}{R_1 \frac{R_4}{R_2} - R_{30}} = \alpha \frac{d\, I_l}{I_l}.$$

The line current will change with changed external conditions. In order to restore the line current to its former value, it is only necessary to change the measured quantity A_X by a certain amount δA_X. Let us consider the ratio of quantity δA_X to the nominal value of the measured quantity A_{nom} as an additional referred error due to the influence of external factors:

$$\gamma = \frac{\delta\, A_x}{A_{nom}} = \frac{\delta\, A_x}{A_x} \cdot \frac{A_x}{A_{nom}} \simeq \alpha \frac{\delta\, I_l}{I_l} \cdot \frac{A_x}{A_{nom}}.$$

By changing from the infinitely small quantities to finite increments, the relative referred error of the system due to the influence of external factors can be written in the form

$$\gamma \simeq \frac{\alpha}{K+1} \cdot \frac{A_x}{A_{nom}} \left(\frac{\delta\, \kappa_u}{\kappa_u} + \frac{\delta\, I_{aux}}{I_{aux}} - \frac{\delta\, z_o}{z_o} \right).$$

At K = 25-30 (see above) external factors have but a small influence on the system accuracy.

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DESIGN OF ELECTROMAGNETIC RECORDING INSTRUMENTS

K. S. Poluliakh

A circuit analysis based on power relations existing in the circuits is the latest tendency in the design of electrical measuring instruments. This method of analysis was employed in a number of works such as [1], and others.

In the present paper a method of designing recording electromagnetic instruments based on the analysis of power relations is proposed.

In designing electromagnetic instruments the torque is usually determined on the basis of the Q-factor. This can only be done, however, if the moment of friction is determined by the weight of the moving part, i.e., by the friction in the bearings. In recording instruments the moment of friction is determined in the main by the friction of the pen on paper and cannot be expressed in terms of the moving part weight; hence, determining the optimum weight of the winding is pointless in this instance, and it is more expedient to find the nominal torque M experimentally on the basis of permissible variations in the readings.

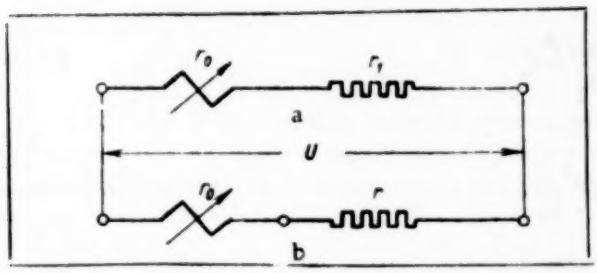

Fig. 1. A circuit of a single range instrument: a) voltmeter; b) ammeter r_0 connected into the circuit with resistance r.

Let us assume that the weight and dimensions of the coil, and hence the moment of inertia J of the moving system is the same for all the limiting conditions of measurement and is fixed.

It is known [2] that for recording instruments it is most expedient to ensure a certain degree of damping $\beta = 0.65$–0.7. Moreover, the damping coefficient ψ should be

$$\psi = 2\beta\sqrt{JM_y}$$

where M_y is the specific restoring moment.

Thus, for a given construction of the instrument its torque M, damping coefficient ψ, coil area S, the length of the mean turn l and the cross-sectional area Q of the winding must be independent of the range of measurement. Above quantities are basic for the design of instruments.

With constant coil dimensions the ampere turns WI become a single-valued function of the power P_0 dissipated in the coil [1]:

$$P_0 = I^2 r_0 = I^2 \rho \frac{lW^2}{kQ} = k_1 (IW)^2, \qquad (1)$$

where r_0 is the coil resistance; ρ is the resistivity of the wire; k is the stacking factor; W is the number of turns; and I is the coil current.

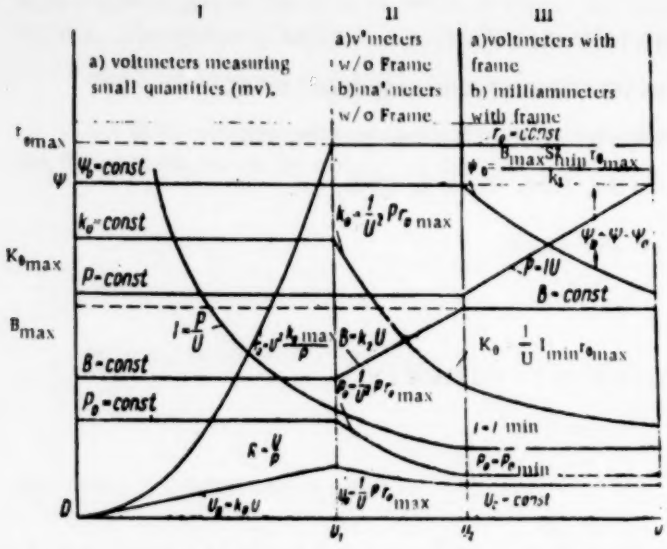

Fig. 2. Graph showing the relation between the voltmeter parameters and its range U.

Coefficient k is practically independent of the wire diameter for wires of medium diameters. When a very thin wire is used, the winding copper cross section kQ should be taken as constant instead of the area Q.

The coil ampere turns are determined by the flux density B in the working airgap according to the formula

$$M = BSWI, \qquad (2)$$

since S and M are given. Hence, power P_0 dissipated in the coil will change inversely to flux density B. The flux density B, however, cannot be made indefinitely large since this may lead to excessive damping.

The damping coefficient of the instrument is a sum of two terms:

$$\psi = \psi_0 + \psi_\partial, \qquad (3)$$

where ψ_0 is the damping coefficient due to the coil; ψ_∂ is the damping coefficient due to additional damping such as the frame, short circuited turns, magnetic or air damping.

Let us find the relationship between the flux density B and the damping coefficient of the coil ψ_0.

Let us denote

$$k_0 = \frac{r_0}{R_y}, \qquad (4)$$

where R_y is the total resistance of the circuit connected to the coil.

Coefficient ψ_0 is equal to

$$\psi_0 = \frac{(BSW)^2}{R_y}, \qquad (5)$$

From (1), (2), (3), (4) and (5) it is easy to obtain

$$P_0 = k_0 \frac{M^2}{\psi - \psi_\partial}, \qquad (6)$$

From (6), (2) and (1) we obtain

$$B = \sqrt{\frac{(\psi - \psi_\partial) k_1}{S^2 k_0}}. \qquad (7)$$

The relation between the flux density and the damping coefficients (7) can be made the basis of the instrument design.

Design of Single Range Voltmeters (millivoltmeters)

Let us assume that the resistance of the source of voltage U is considerably smaller than that of the voltmeter $r_0 + r_1$ (Fig. 1a), so that it can be written

$$R_y = r_0 + r_1. \qquad (8)$$

From (4) and (8) we easily obtain:

$$k_0 = \frac{U_0}{U} = \frac{P_0}{P}, \qquad (9)$$

where $U_0 = Ir_0$ is the voltage drop across the coil; $U = I(r_0 + r_1)$ is the voltage measured by the voltmeter; $P = I^2(r_0 + r_1)$ is the total power dissipated in the voltmeter.

Power P_0, on the basis of (9) and (4), is equal to

$$P_0 = \frac{k_0^2 U^2}{r_0}. \tag{10}$$

Equating (6) and (10), we obtain

$$k_0 = \frac{M^2 r_0}{(\psi - \psi_\partial) \cdot U^2}. \tag{11}$$

Figure 2 shows graphs of relationships between some of the voltmeter parameters and its range of measurement U.

Let us first examine the case when the flux density B can be made large enough to satisfy condition (7) even with $\psi_\partial = 0$.

If $\psi_\partial = 0$, the power dissipated in the voltmeter does not depend on its range U. This conclusion can be arrived at from (9), (10) and (11):

$$P = \frac{M^2}{\psi} = \text{const}. \tag{12}$$

The voltmeter current changes with the change of the range of measurement

$$I = \frac{P}{U}. \tag{13}$$

It is expedient to choose the instrument parameters in such a way that power P_0 is maximum at given values of P and I. For this purpose, it is necessary to increase W [see (1)], i.e., to wind the coil with the thinnest possible wire. At present, wire of a diameter not less than 0.02-0.03 mm is used. Let us denote the resistance of the coil wound with the thinnest possible wire by $r_{0\,\max}$.

From (7) and (11) we easily obtain:

$$B = U\sqrt{\frac{\psi^2 k_1}{S^2 M^2 r_{0\,\max}}} = k_2 U. \tag{14}$$

Expression (14) shows that under the given conditions flux density must rise proportionately to the measuring range. This, however, is only possible up to a certain limit of B_{max}, determined by technical possibilities. Fig. 2 shows the limit of measurement U_2 (with $\psi_\partial = 0$) corresponding to a maximum possible value of flux density [see (14)]:

$$U_2 = \sqrt{\frac{B^2_{\max} S^2 M^2 r_{0\,\max}}{\psi^2 k_1}} \tag{15}$$

The relation of the additional resistance r_1 to the measuring range has the form:

$$r_1 = \frac{U^2}{P} - r_{0\,\max}. \tag{16}$$

For a decreasing range (with $U < U_2$), r_1 should be decreased. This is only possible down to a certain voltage U_1 determined by the given temperature error:

$$\gamma = \frac{\beta r_0}{r_0 + r_1}, \tag{17}$$

where β is the temperature coefficient of the coil resistance.

At a voltage U_1, coefficient k_0 has its maximum value $k_{0\,\max}$ obtained from a simultaneous solution of (4), (8), and (17):

$$k_{0\,\max} = \frac{\gamma}{\beta}. \tag{18}$$

Quantity U_1 can be found by inserting $k_{0\,max}$ into (11):

$$U_1 = \sqrt{\frac{M^2 r_{0\,max}^{\beta}}{\psi \gamma}}. \tag{19}$$

For the $U_1 < U < U_2$ ranges of measurement, the following relations hold

$$k_0 = \frac{P r_{0\,max}}{U^2} \tag{20}$$

[see (11) and (12)];

$$P_0 = \frac{P^2 r_{0\,max}}{U^2} \tag{21}$$

[see (9) and (20)];

$$U_0 = \frac{P r_{0\,max}}{U} \tag{22}$$

[see (9)].

In designing an instrument for a measuring range $U_1 < U < U_2$, it is necessary to choose a diameter for the coil wire and to determine $r_{0\,max}$ and W:

$$r_{0\,max} = \rho \frac{l k Q}{q^2}, \tag{23}$$

$$W = \frac{k Q}{q}, \tag{24}$$

where q is the cross section area of the wire.

Next, flux density B should be determined from (14) and current I from (2). The calculation of the remaining parameters is clear from the preceding.

Let us examine design relationships for ranges lower than U_1 (Fig. 2). In this range it becomes necessary to decrease the coil resistance r_0 by increasing the wire diameter in order that the temperature error should not exceed the permissible value. Coefficient k_0 should have, in this range, the value of $k_{0\,max}$ and the flux density B must equal B_{min} determined from (7) and (18):

$$B_{min} = \sqrt{\frac{\psi k_1 \beta}{S^2 \gamma}}. \tag{25}$$

From (11) and (12) we find:

$$r_0 = U^2 \frac{k_{0\,max}}{P}, \tag{26}$$

Power P_0 and the voltage drop U_0 across the coil are determined from (9).

The design of voltmeters and milliammeters for ranges lower than voltage U_1 is carried out in the following order.

Having determined $k_{0\,max}$ from (18), r_0, q and W are obtained from (26), (23) and (24), respectively. Having calculated the flux density B_{min} from (25), the current I is found from (2).

Let us find the design relationships for the third section of the graph (Fig. 2) corresponding to ranges higher than voltage U_2.

The extension of the range above U_2 is carried out by increasing the additional resistance r_1 at a constant resistance of the coil $r_{0\,max}$, current I_{min} and flux density B_{max}. At the same time, quantity k_0 decreases. In order to meet the damping conditions (7) additional damping ψ_∂ must be introduced. The value of the coefficient ψ_∂ can be determined from (7):

$$\psi_\partial = \psi - \frac{B^2_{max} S^2 k_0}{k_1}. \tag{27}$$

The relation between k_0 and U for the third section can be obtained from (9):

$$k_0 = \frac{1}{U} I_{min} r_{0max}. \tag{28}$$

The total power dissipated in the instrument is equal to

$$P = UI_{min}.$$

The damping coefficient of the coil ψ_0 is determined from (7) and (28):

$$\psi_0 = \psi - \psi_\partial - \frac{1}{U} \cdot \frac{B^2 max S^2 I_{min} r_{0\,max}}{k_1}.$$

In the third section quantities P_0 and U_0 do not depend on the range since $r_{0\,max}$ and I_{min} remain constant.

The design of voltmeters for ranges higher than U_2 are carried out in the following sequence.

Having chosen a minimum diameter for the wire, $r_{0\,max}$ and W are determined from (23) and (24). Having selected a maximum flux density B_{max}, the voltmeter current I_{min} is determined from (2). Having calculated k_0 from (28), ψ_∂ is determined from (27) and an additional damping of the required type is selected. At the same time, it should be borne in mind that the introduction of an additional damping will produce a certain rise in ψ due to an increase in the moment of inertia of the moving system J.

Thus, the power dissipated by the voltmeter in the first section is determined by the temperature error γ, in the second section by the conditions of damping, and in the third by the value of the maximum flux density B_{max} which can be attained in practice.

Before designing voltmeters, section boundaries (Fig. 2) should be found, i.e., U_1 and U_2 should be determined from (19) and (15).

Design of Ammeters (Milliammeters) Without a Shunt

Figure 1b shows an ammeter r_0 connected in the circuit whose resistance is equal to r. In comparing Fig. 1a and 1b it is easy to see that the conditions of operation of an ammeter without a shunt and a voltmeter do not differ if resistance r (Fig. 1b) is considered as a building-out resistor. The reasoning and design technique used for voltmeters can obviously be also applied to Fig. 1b. Any differences in the course of the design will be determined by the initial conditions for the design of ammeters and voltmeters.

The nominal measured current I is the initial quantity in the design of ammeters (milliammeters). In some instances coefficient k_0 can also be an initial parameter. For the circuit in Fig. 1b,

$$k_0 = \frac{r_0}{r_0 + r}. \tag{29}$$

Quantity k_0 can be determined by the requirements of temperature compensation or from condition $r \gg r_0$. The latter is necessary when the insertion of the instrument must produce only an insignificant effect on the circuit where the current is to be measured.

Sometimes the nominal current I and the circuit resistance r are given (Fig. 1b). In such a case, by multiplying the numerator and the denominator of (29) by I^2 we obtain

$$k_0 = \frac{P_0}{P_0 + I^2 r}. \tag{30}$$

Simultaneously solving (6), (7), and (30), we find

$$B = \sqrt{\frac{k_1 M^4}{S^2 M^2 - I^2 r S^2 (\psi - \psi_\partial)}} \tag{31}$$

The calculations are carried out in the following manner. With given I and r from (31) or (7), flux density B is found if k_0 is known. At the same time, it is considered that $\psi_\partial = 0$, assuming that the operation of the instrument being designed corresponds to the second section of Fig. 2. Having determined W from (2) we find the wire cross section according to (24).

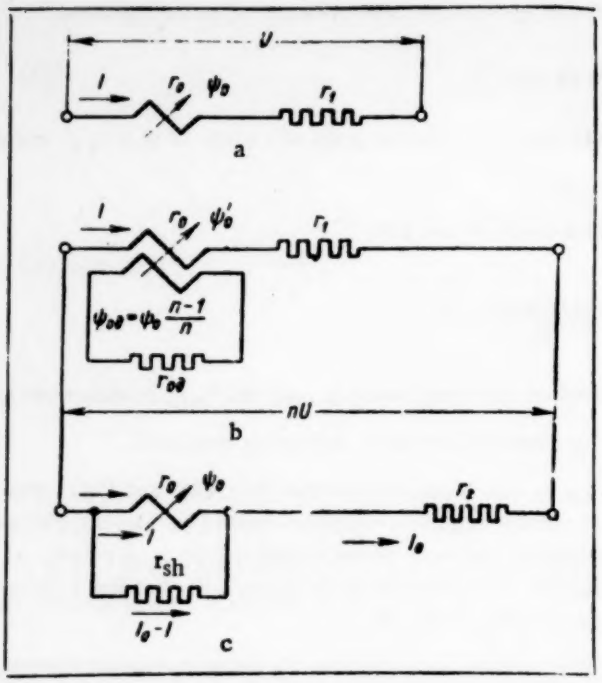

Fig. 3. A circuit of multirange voltmeters: a) circuit of the lowest range; b) circuit for extending the range by means of an additional damping winding; c) circuit for extending the range by means of a shunted coil.

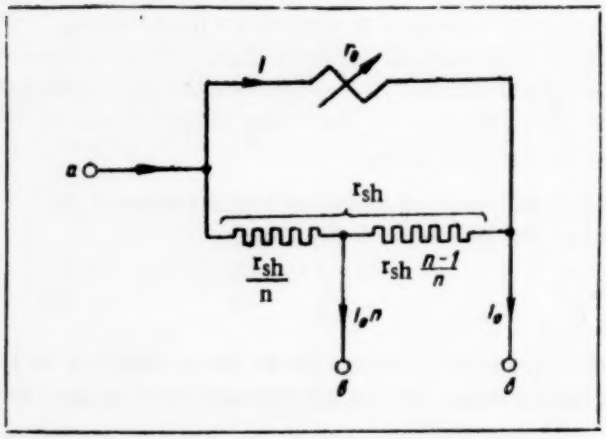

Fig. 4. A circuit of a multirange ammeter.

If the calculation of B from (7) or (31) shows that $B > B_{max}$, it means that the ammeter is working under conditions of section three, Fig. 2, and additional damping ψ_∂ is required. In this case, it is assumed that $B = B_{max}$ and ψ_∂ is found from (7) or (31) and then the additional damping is calculated. Further calculations are carried out in the same way as before.

It should be noted that with rigid damping conditions recording ammeters can only be used without shunts in circuits of a definite resistance. In general, ammeters with shunts, consuming greater power, have to be used.

Design of Multirange Voltmeters

Let us assume that a voltmeter has been designed for the lowest range (Fig. 3a). Let the damping coefficient of the coil be equal to ψ_0. The extension of the range n times is accomplished by adding of a series resistance r_2 (Fig. 3b) at a constant current I through the voltmeter. This will cause a drop in ψ_0 to the value ψ_0'. By examining (5) and (8) it is easy to see that

$$\psi_0' = \frac{\psi_0}{n}.$$

In order to fulfill the damping conditions it is possible to add a winding to the coil and to connect it to resistance $r_{0\partial}$ (Fig. 3b), whose value will depend on the value of the range. The damping coefficient $\psi_{0\partial}$ of the additional winding must be equal to

$$\psi_{0\partial} = \psi_0 - \psi_0' = \psi_0 \frac{n-1}{n}.$$

The calculation of the parameters of an additional coil with a known $\psi_{0\partial}$ does not present any difficulties.

The damping condition can also be fulfilled by shunting the coil with a resistance r_{sh} (Fig. 3c), whose value depends on the value of the range.

Let us assume that the lowest range of a voltmeter has been calculated by one of the methods described above (Fig. 3a). The extension of the range is attained by increasing the series resistance by r_2 and shunting the coil by r_{sh} (Fig. 3c). The calculation is reduced to determining the values of r_2 and r_{sh}. The voltage drop in Fig. 3c is n times greater than that of Fig. 1a:

$$nI(r_0 + r_1) = I_0 \left(r_1 + r_2 + \frac{r_0 r_{sh}}{r_0 + r_{sh}} \right) \qquad (32)$$

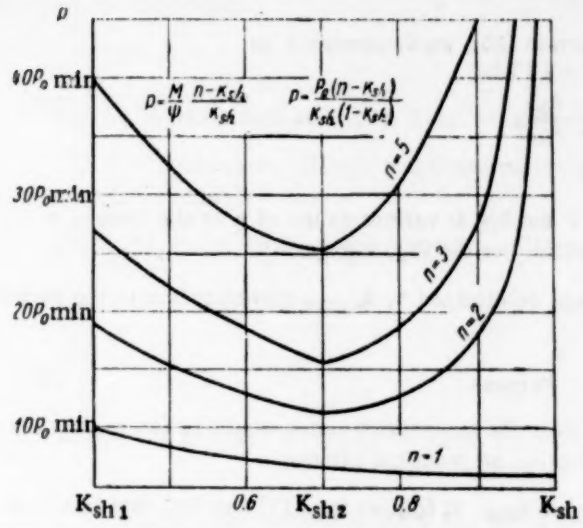

Fig. 5. Graph showing the relation between the total power P consumed by the ammeter and k_{sh} for various values of n.

For the circuit in Fig. 3c it is obvious that

$$Ir_0 = (I_0 - 1)r_{sh} \qquad (33)$$

In order to fulfill the damping conditions, it is necessary to have coils in Fig. 1a and 1c connected to equal resistances, i.e.,

$$r_1 = \frac{r_{sh}(r_1 + r_2)}{r_1 + r_2 + r_{sh}} \qquad (34)$$

By simultaneously solving (32), (33), and (34), we find

$$r_{sh} = \frac{r_1 n}{n-1} = \frac{r_0 n(1-k_0)}{k_0(n-1)}, \quad r_2 = r_1(n-1) = \frac{r_0(1-k_0)(n-1)}{k_0}, \text{ where } k_0 = \frac{r_0}{r_1 + r_0}.$$

It is known from [3] that in the case when the resistance of the coil alone depends on temperature, the following relationship holds

$$\gamma = \frac{\beta r_0}{R_y}.$$

When the range is extended according to circuit Fig. 3c, the resistance of the circuit closing the coil remains constant. Hence, the temperature error is independent of the range.

The circuit (Fig. 3c) obviously dissipates greater power than the Fig. 3b circuit at the same measured voltage. By denoting the power dissipated in Fig. 3b and 3c by P_1 and P_2, respectively, we can easily see that

$$P_2 = \left[\frac{n - k_0}{n(1 - k_0)}\right]^2 P_1.$$

Design of Shunted Ammeters

Let the extension of the range of an ammeter be attained by means of a shunt (Fig. 4). In calculating damping, let us assume that the coil is connected only to resistance r_{sh} since the circuit resistance, into which the ammeter works, is large compared with the shunt r_{sh}.

For the Fig. 4 circuit coefficient, k_0 equals

$$k_0 = \frac{r_0}{r_0 + r_{sh}}.$$

Let us introduce the notation

$$k_{sh} = \frac{I}{I_0} = \frac{r_{sh}}{r_{sh} + r_0}, \qquad (35)$$

where I_0 is the current in the external circuit when the instrument is connected to the circuit by means of terminals a and b (Fig. 4).

It is obvious that

$$k_0 = 1 - k_{sh}. \qquad (36)$$

In order to increase the measuring range n times, the instrument is connected by means of terminals a and c (Fig. 4). The shunt resistance is thus decreased to 1/n-th of its value. The total power P consumed by the circuit when the nominal current $I_0 n$ is flowing through it is equal to

$$P = I^2\left(r_0 + r_{sh}\frac{n-1}{n}\right) + (I_0 n - I)^2 \frac{r_{sh}}{n}.$$

Substituting for I_0 and r_{sh} the values obtained for them in (35), we determine P as

$$P = \frac{P_0 (n - k_{sh})}{k_{sh}(1 - k_{sh})}, \tag{37}$$

where $P_0 = I^2 r_0$.

Figure 5 shows the relation between the total power P and k_{sh} at various values of n in the form of a graph. Fig. 5 graph can be divided into three sections, similarly to the Fig. 2 graph.

The first section comprises values of k_{sh} from 0 to k_{sh1} determined by $k_{0\,max}$ corresponding to the permissible temperature error

$$k_{sh1} = 1 - k_{0\,max}. \tag{38}$$

In practice, there cannot be $k_{sh} < k_{sh1}$ since in that case the temperature error would be larger than the permissible one. Hence, the examination of the first section has no practical interest.

The second section comprises values of k_{sh} from k_{sh1} to k_{sh2}. It follows from (7) and (36) that flux density B will rise with k_{sh} and become largest at $\psi_\partial = 0$. The flux density will reach its maximum $B = B_{max}$ at $k_{sh} = k_{sh2}$ determined from (7) and (36) as

$$k_{s2} = 1 - \frac{\psi k_1}{B^2_{max} S^2}. \tag{39}$$

With a further rise in k_{sh} from k_{sh2} to 1, the flux density B remains constant ($B = B_{max}$), and in order to fulfill the damping condition additional damping ψ_∂ is introduced.

Thus, P_0 = const only in the third section where the flux density value and hence P_0 remain constant at

$$P_0 = P_{0\,min} = \text{const}.$$

The relation between P and k_{sh} in the second section of Fig. 5 can be found from a simultaneous solution of (7), (36) and (37) at $\psi_\partial = 0$:

$$P = \frac{M}{\psi} \cdot \frac{n - k_{sh}}{k_{sh}}.$$

It follows from the graphs thus obtained that with a given construction an ammeter consumes minimum power at $k_{sh} = k_{sh2}$ and at a minimum n. The nominal current I_1 of a shunted instrument can be expressed as follows [see (35)]:

$$I_1 = I_0 n = \frac{I n}{k_{sh}}. \tag{40}$$

Since for minimum power consumption it is advisable to make n as small as possible, it becomes expedient to ensure as large a current as possible $I = I_{max}$. Obtaining I_{max} from (24) and (2), and taking the largest possible cross-sectional area for the wire q_{max}, we have

$$I_{max} = \frac{M q_{max}}{B_{max} S k_1 Q}. \tag{41}$$

On the basis of the above it is possible to recommend the following method of shunted ammeter design.

Having determined k_{sh2} from I_{max} from (39) and (41), n is determined from (40). If n comes to less than one ($n < 1$), it is taken to equal one ($n = 1$), and I is determined from (40), then W and q are determined in that sequence from (2) and (24). Having calculated r_0 from (23), resistance r_{sh} is found from (35). From a known value of n the remaining parameters are then found.

If the instrument is a single range one, this ends the calculations. In the case of a multirange instrument, shunts are calculated for the remaining measuring ranges.

The technique described above is suitable for designing instruments with an optimum damping and minimum power dissipation.

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A CIRCUIT FOR MEASURING THE REAL COMPONENT OF AN IMPEDANCE

K. B. Karandeev and G. A. Shtamberger

The existing methods of measuring a real component of an impedance in the range of audio and higher frequencies are based, as a rule, on balanced bridge circuits or differential transformer circuits whose disadvantage lies in the necessity of balancing both components of Z (X and R) even when only one of them is required. The last circumstance obviously complicates the measurement and makes balancing dependent on variations in the component which is not being measured.

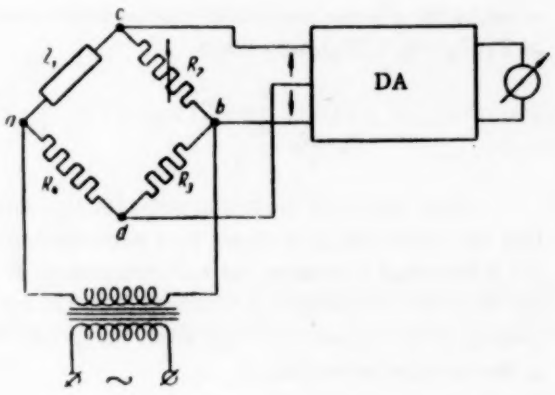

Fig. 1

Among other methods employed, especially for radio measurements, one should note the ammeter and voltmeter methods in various forms,and methods based on substitution, real component variation, tuning, etc. In view of their complicated measuring technique, subsequent cumbersome calculations, and a relatively low accuracy, these methods lack the potentialities for universal application.

For various production measurements, including measurements of nonelectrical quantities, in radio engineering under workshop conditions in large-scale production control, it is convenient to have circuits capable of measuring separately and independently the Z-components with an error not exceeding 0.5-1.0%. One such circuit proposed in [1] consists of a semi-balanced bridge with a phase-sensitive indicator for an independent measurement of the real component. One of the disadvantages of this circuit is that the value of one of the voltages impressed on the indicator input depends on the relation between the real and imaginary components of the impedance being measured. Hence, the sensitivity of the circuit as a whole changes not only due to the sensitivity of the bridge, but also as a result of variations of the voltage impressed on the indicator input which, in turn, depends on the phase angle of the measured impedance.

Below we describe a circuit (Fig. 1) which provides constant sensitivity over a sufficiently wide range of phase angle variations,due to the fact that the voltages impressed on the indicator input do not depend on the relation between the reactive X and resistive R components of the measured impedance.

The circuit consists of a deliberately unbalanced bridge with an electronic differential phase-sensitive ac indicator,which has a high input impedance (of the order of several megohms) [2], whose readings are determined by relationship

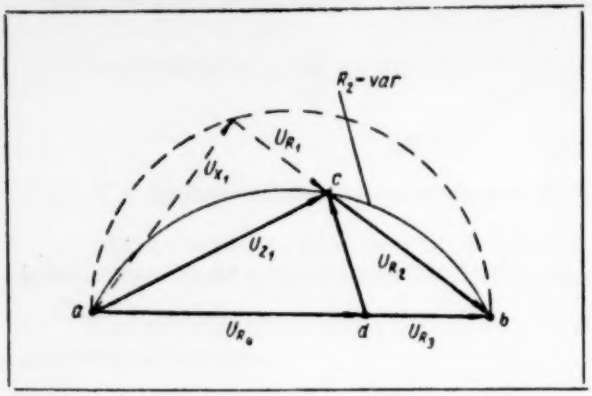

Fig. 2

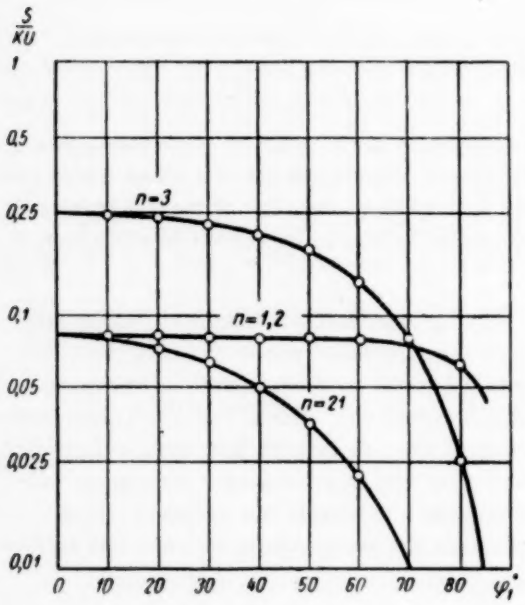

Fig. 3

$$I = K(|U_1| - |U_2|) = K\Delta U, \qquad (1)$$

where K is a coefficient depending on the indicator stimuli and $|U_1| = |U_{dc}|$ and $|U_2| = |U_{db}|$ are the moduli of the voltages impressed on the indicator input terminals.

The indicator pointer is brought to zero by adjusting one of the bridge arms (R_2, R_3, R_4).

In this case, $I = 0$ and

$$|U_1| = |U_2|. \qquad (2)$$

The voltages impressed on the indicator input will assume in terms of circuit parameters the form of

$$U_1 = U_{dc} = U\frac{Z_1R_3 - R_2R_4}{(Z_1+R_2)\cdot(R_3+R_4)}, \qquad (3)$$

$$U_2 = U_{db} = U\frac{R_3}{R_3+R_4}, \qquad (4)$$

where U is the bridge supply voltage.

By substituting (3) and (4) in (2), we can write:

$$U\left|\frac{Z_1R_3 - R_2R_4}{(Z_1+R_2)\cdot(R_3+R_4)}\right| = U\left|\frac{R_3}{R_3+R_4}\right|,$$

whereby for a series equivalent circuit substitution of $Z_1 (Z_1 = R_1 + jX_1)$, we obtain

$$R_1 = R_2\frac{\left(\frac{R_4}{R_3} - 1\right)}{2}. \qquad (5)$$

Thus, when the moduli of voltages U_{dc} and U_{db} are equal, which is shown by a zero reading of the differential indicator, the real component of the measured impedance is obtained from (5) according to the values of bridge arms, independently of the reactive component.

If R_2 is made variable, and ratio $n = R_4/R_3$ made equal to 3 (obviously at $n \leq 1$ the circuit is unsuitable for measuring), the quantity R_1 is determined directly from R_2:

$$R_1 = R_2.$$

A bridge circle diagram for an inductive impedance and condition $n = 3$ is given in Fig. 2. It follows from the diagram that with a fixed position for point d the value of U_{db} is determined only by the bridge supply voltage. In order to bring the indicator to zero it is necessary to adjust by means of R_2 the second voltage U_{dc} to equal U_{db}, which makes the compared voltage moduli independent of the relation between the real and imaginary components of Z, and keeps the indicator sensitivity constant. Thus, the indicator's conditions of operation are opportune, which cannot be said for the circuits described in [1] and [3].

Let us determine the relative circuit sensitivity with respect to R_1. This condition is fulfilled by expression

$$S = \frac{Kd\,(|U_{dc}| - |U_{db}|)}{dR_1}R_1. \qquad (6)$$

By substituting the moduli of expressions (3) and (4) in (6), and taking (5) into consideration, we obtain:

$$S=\frac{KUR_2}{R_2\frac{(n-1)}{2}+2R_2+\frac{X_1^2+R_2^2}{R_2\frac{(n-1)}{2}}}=\frac{2KU(n-1)}{(n+1)^2+(n-1)^2\operatorname{tg}^2\varphi_1}, \tag{7}$$

where φ_1 is the phase angle of the measured impedance.

By analyzing (7) it is easy to show that the maximum sensitivity is obtained when n = 3 and tan $\varphi_1 = 0$.

In Fig. 3 the circuit sensitivity is plotted against the impedance phase angle for various values of n. The values of n have been chosen as 1.2, 3, and 21 so as to make the coefficients obtained when these values are inserted in (5) equal to multiples of 10; $R_1 = 0.1R_2$; $R_1 = R_2$, and $R_1 = 10R_2$. It follows from the graph that with a suitable choice of circuit parameters the sensitivity can be made constant over a wide range of ratios of the real and imaginary components of the measured impedance.

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EFFECTIVE AREA OF COILS FOR MEASURING FLUX DENSITY

D. A. Iakovlev

The measurement of flux density on a ballistic galvanometer or milliwebermeter (fluxmeter) is made by means of a measuring coil. The constant of a coil is the product of the number of turns W by its effective area S_{eff}.

It is useful to know the effective area of the most commonly used coils, those of a round and rectangular shape.

1. A round (straight cylindrical) coil with an evenly distributed winding has a constant determined by the formula

$$WS_{eff}=\int_0^W S(r)\,dW=\int_{r_0}^{r_1}\pi r^2\,\frac{W}{r_1-r_0}\,dr=$$
$$=\frac{1}{3}\pi\left(r_1^2+r_1r_0+r_0^2\right)W.$$

Whereby the effective area of such a coil is equal to:

$$S_{eff}=\frac{\pi}{3}\left(r_1^2+r_1r_0+r_0^2\right). \tag{1}$$

where r_1 is the external radius of the coil and r_0 its internal radius.

2. The effective area of a rectangular coil with an evenly distributed winding, by virtue of reasoning similar to the preceding, is

$$S_{\text{eff}} = 2a_0 b_0 + (a_0 + b_0)\cdot\Delta + \frac{4}{3}\Delta^2, \tag{2}$$

where

$$2\Delta = a_1 - a_0 = b_1 - b_0.$$

Here, a_1 and b_1 are the external length and width of coils, a_0 and b_0 the internal length and width, and Δ the thickness of the winding.

3. Taking into consideration the rounded-off edges of the rectangular coil, we obtain

$$S_{\text{eff}} = 2a_0 b_0 + (a_0 + b_0)\cdot\Delta + \frac{\pi}{3}\Delta^2. \tag{3}$$

By means of the above formulas it is possible to calculate the error in calculating the effective area of coils when approximate formulas are used.

The error in calculating the effective area of a round coil does not exceed 5% when the following approximate formulas are used:

$$S_{\text{eff}} = \pi r_0^2, \quad \text{if} \quad r_1 \leqslant 1.05\, r_0;$$
$$S_{\text{eff}} = \pi\left(\frac{r_1 + r_0}{2}\right)^2, \quad \text{if} \quad r_1 \leqslant 1.1\, r_0;$$
$$S_{\text{eff}} = \pi r_1 r_0, \quad \text{if} \quad r_1 \leqslant 1.5\, r_0.$$

For rectangular coils the most common approximate formula is the following:

$$S_{\text{eff}} = 0.25(a_1 + a_0)\cdot(b_1 + b_0) = 2a_0 b_0 + (a_0 + b_0)\Delta + \Delta^2. \tag{4}$$

The error in calculation by (4) depends on the relative ratios of a_0, b_0 and Δ. For the majority of rectangular coils used in practice, however (when $\Delta < a_0$ and $\Delta < b_0$), the error of calculating the effective area by (4) is negligibly small and for a given effective area it decreases with a decreasing ratio a_0/b_0.

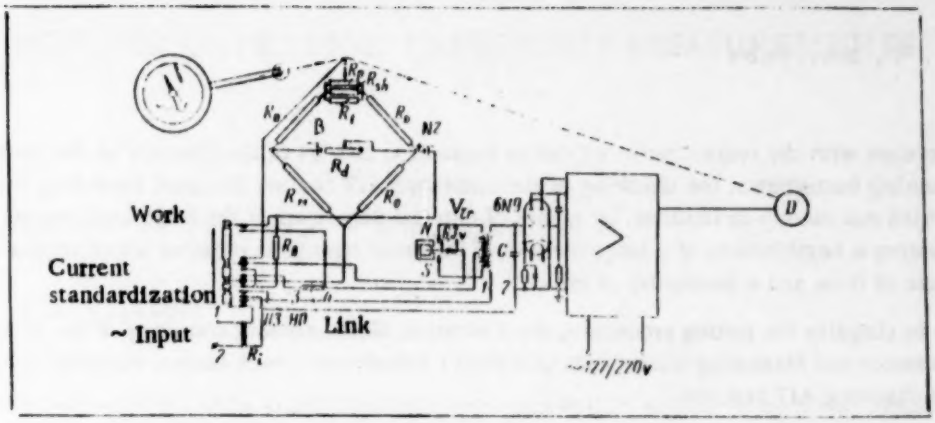
MEASURING OF AC CURRENTS AND VOLTAGES BY A COMPENSATING METHOD

V. S. Lerner and Iu A. Kornil'tsev

For automatic monitoring and control of a number of processes, it is required to measure and regulate ac currents and voltages with a great degree of accuracy. The instruments produced by our industry are not suitable for such measurements.

This problem can be solved by using an ordinary automatic potentiometer with certain changes in its circuit.

The measuring method consists in the following. The measured alternating voltage (in the case of current, a shunt is connected), is automatically compensated by means of a voltage obtained from a dc automatic potentiometer circuit and converted to an alternating voltage by means of a vibrating transducer. The difference between these two voltages, after amplification, controls a motor which drives the slide-wire contact controlling the compensating voltage and moves a pointer and a pen.



This method is only suitable for measurement of ac voltages and currents whose phase coincides with that of the vibrating transducer excitation.

The automation laboratory of theVNII Tsvetmet tried out the above method of measuring by means of an EPD-17 potentiometer (see figure). Tests showed that a sufficiently small error of measurement can be attained, which was of the order of 0.5%.

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EQUIPMENT FOR CHECKING AIT TEST SETS

A. V. Martynov

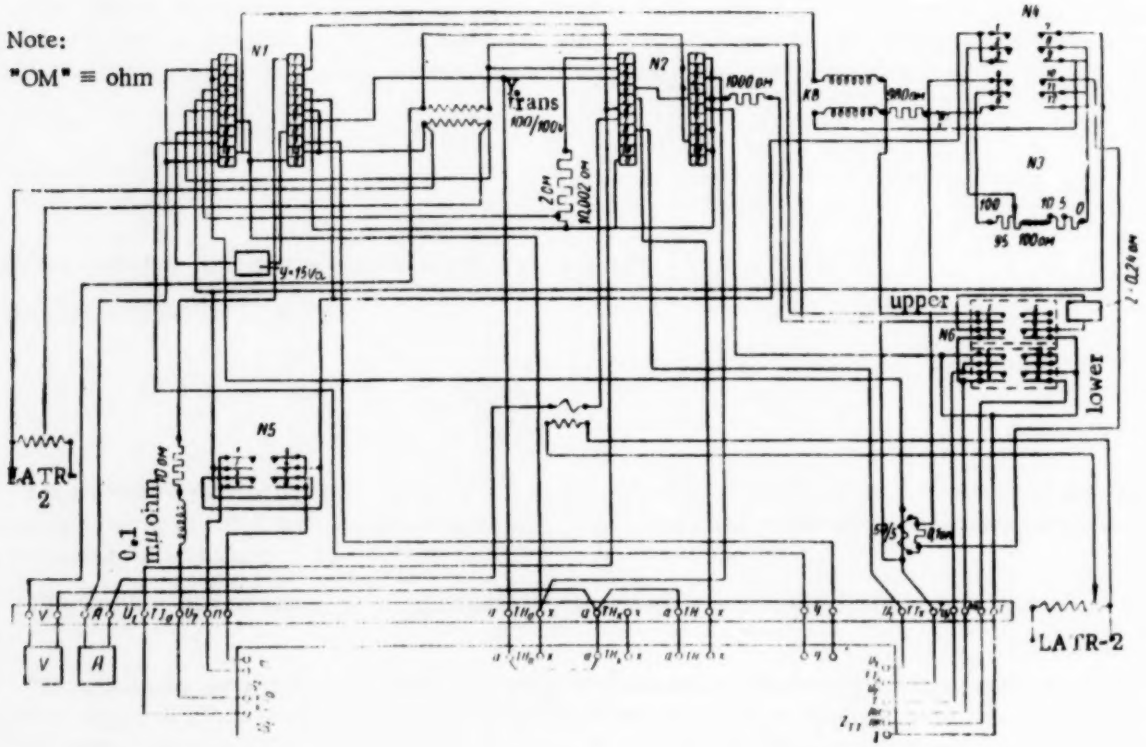
In accordance with the requirements set out in instruction 183-54 of the Committee for Standards, Measures and Measuring Instruments, the checking of the combined AIT test set designed for testing measuring transformers, is carried out mainly in sections, by means of determining errors of the basic components. With such a method of testing a combination of a large number of different circuits is required which results in a considerable expenditure of time and a possibility of errors.

In order to simplify the testing procedure, the Electrical Measurement Laboratory of the Khar'kov State Institute of Measures and Measuring Instruments (KhGIMIP) introduced a rack testing assembly, developed by the author, for checking AIT test sets.

The circuit of this equipment is given in the figure. Switches 1 and 2 are modified switches, type MP-10. Switch 3 consists of a box of 20 resistors of 5 ohms each, of an accuracy of 0.1%.

Switches 4, 5 and 6 are 5 amp telephone-type switch-keys. The circuit also includes a current transformer 50/5 amp, class 0.2, a standard resistance spool of 0.1 ohm, a mutual inductance coil of 0.001 henries, a voltage transformer 100/100 v, class 0.5, and a resistor of 10,002 ohms.

By means of this equipment it is possible to check the main measuring circuits of the AIT set, i.e., to check 1) ammeters; 2) "current" drop indicators; 3) voltmeters; 4) "voltage" drop indicators; 5) scale designations for voltage transformers; 6) scale designations for conductances; 7) voltage conversion transformers; 8) scale designations for resistances; 9) scale designations for current transformers; 10) scales of cophasal slide-wires; and 11) scales of square-law slide-wires.



HIGH AND ULTRAHIGH FREQUENCY MEASUREMENTS

PHASE STABILITY OF FREQUENCY MULTIPLIERS

M. Z. Kliumel'

The investigation of the phase stability of frequency multipliers appears to be a very important problem of metrology in connection with the realization of high-stability microwave systems based on molecular resonance absorption and emission in different substances. This is connected with the fact that the frequency errors introduced by the multipliers, and also the widening of the spectral line, may lower the accuracy of comparison of the frequency of the above-mentioned systems with the frequency of a quartz standard.

In [1] a method of experimental investigation of the phase stability of frequency multipliers was described and the preliminary results were surveyed. In [2] the apparatus was described and the results of the investigation briefly evaluated. This paper briefly describes the final results of an experimental investigation, presents a general form of the frequency error at the output of the multiplier, and gives an expression for the energy spectrum of the output oscillation.

Experimental Section

It was established in [2] that the relative widening of the line $\Delta F/f$, introduced by the frequency multiplier with the coefficient of multiplication $9 \cdot 10^4$, does not exceed $5 \cdot 10^{-10}$.

Further multiplication of the frequency, or increase of the resolving power of the spectrum analyzer, for the purpose of refining the results, is connected with great difficulties, and proved to be practically impossible.

We succeeded in increasing the resolving power of the arrangement 25-fold without creating any additional complicated equipment for that purpose. The block diagram of the experimental arrangement is shown in Fig. 1. Here 1 is the circuit shown in Fig. 8 of [2], except that the modulation circuit has been changed, and a quartz generator with frequency very close to that of the master oscillator, i.e., $f_m = 100$ kc + Δ, is used as modulator. Furthermore, the spectrum analyzer was transferred to the end of the block diagram. We shall not deal here with the functioning of that part of the circuit, since it has already been described.

The amplitude of the obtained beat frequency 100 kc + Δ is amplified by the amplifier 2 to the magnitude of 2 v, which is sufficient for driving an additional frequency multiplier. The final output voltage of the frequency 2.5 Mc + 25Δ (the multiplication factor of the additional multiplier is 25) is fed into the mixer 4 together with the voltage of the frequency 2.5 Mc from the multiplier No. 01 (see Fig. 8 of [2]). The separated voltage of low frequency 25Δ is amplified in the narrow band amplifier 5 and fed to the spectrum analyzer 6. For monitoring, the investigated voltage is observed on the oscillograph 7.

As a result of numerous measurements, it appeared that there is no widening of the line. Therefore, it can be concluded that if the multipliers produced a widening of the spectral line then, with the multiplication factor equal to $2.25 \cdot 10^6$, the relative value of the widening of the line is $(\Delta F/f) < 2 \cdot 10^{-11}$.

This result supports the assertion that the multipliers do not contain any mechanism resulting in an abnormally large phase modulation at frequencies close to zero. In other words, if we have at the input of the multiplier a purely sinusoidal oscillation, then the spectrum of the output wave form will contain the δ-function and continuous noise spectrum; also, the power of the noise spectrum in the vicinity of the carrier frequency is much smaller than the power of the carrier.

The results of the experimental investigation (see, also, [2]) make possible a theoretical definition of the frequency error introduced by the multipliers and an analytical expression of the spectrum of the output signal.

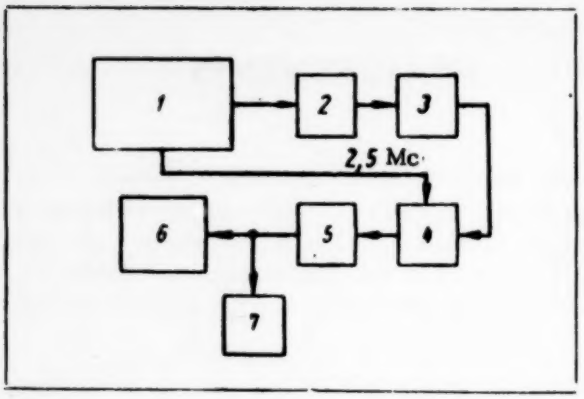


Fig. 1

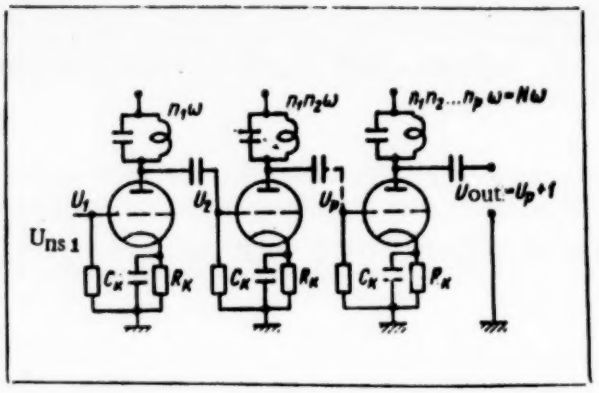


Fig. 2

Determination of the Frequency Error Introduced by the Multipliers and of the Output Oscillation Spectrum

In [1] and [2] the results of the investigation of the frequency error were given, connected with slow changes of the parameters of the circuit whose statistics are unknown to us.

In the following we investigate the passage of a signal in the presence of noise, whose statistics are known.

Consider an arbitrary system of p stages of frequency multiplication, representing nonlinear amplifiers. To simplify the analysis we assume that all stages work in the region of amplitude limitation, so that we can neglect the fluctuations of the amplitude.

The simplified diagram of p multipliers is shown in Fig. 2. To the input of the first stage is fed the oscillation $U_1 = U_1(t)\cos[\omega_0 t + \varphi(t)]$, the amplitude and phase of which is modulated at random, and shot noise of the preceding stage U_{ns1} in the frequency range $\omega_0 \pm \Delta\omega$.

It appeared very advantageous to consider beats originating from the superposition of these oscillations,

$$U_1(t)\cos[\omega_0 t+\varphi(t)] + U_{ns\,1}(t)\cos[\omega_0 t+\psi_1(t)] \qquad (1)$$

(for simplicity we assume that the preceding stage is tuned exactly to the generator frequency).

As a result of a simple transformation, taking into account that $\overline{U_{ns1}^2} \ll \overline{U_1^2}$, we obtain the following relation:

$$U_1(t)\cos\,[\omega_0 t + \varphi(t)] + U_{ns1}(t)\cos\,[\omega_0 t + \psi(t)] \simeq \qquad (2)$$

where

$$m_1(t) = \frac{U_{ns1}(t)}{U_1(t)} \simeq \frac{U_{ns1}(t)}{\overline{U_1(t)}}. \qquad (3)$$

It is further necessary to take into account the influence of the noise of the first stage on the phase of the multiplied oscillation.

In [2] the statistical phase characteristics of the multiplier were obtained, and a sharp dependence was established of the phase of the output oscillation on the magnitude of the grid bias $\varphi = \varphi(U_g)$. Obviously, the low-frequency components of the fluctuations of the anode voltage and the thermal noise of the cathode resistance create noise voltage in the frequency band passed by the cathode circuit $R_k C_k$ (from $f_1 = 0$ to $f_2 = f_{max}$), which modulates the phase of the output oscillation in accordance with the characteristics $\varphi = \varphi(U_g)$. This statement is valid as long as $f_{max} \ll f$ (f is the frequency of the fundamental oscillation).

Such an account of the influence of the internal noise is quite useful, since it eliminates the necessity of a solution of a complicated problem of the dependence of the slow components of the noise on the characteristics of the tubes and on the values of the interelectrode capacities connected with the distribution of the space charge. The method of utilization of the phase characteristics also makes it unnecessary to have definite characteristics of the multiplier.

For convenience we shall conditionally relate all the phase changes to the input. It is sufficient, therefore, to divide the corresponding phase deviations by the multiplication factor.

We shall denote by $U_{nr_1}(t)$ the noise voltage generated across the cathode resistance, and by $\varphi_1 = \varphi_1(U_g)$ the phase characteristic of the first stage (referred to the input).

Because of the smallness of the modulating noise voltage $\Delta\varphi_1 = \frac{d\varphi_1}{dU_g} U_{nr_1} = k_1 U_{nr_1}$, i.e., the relation of the instantaneous phase deviation to the noise voltage is linear.

As a result of taking into account the high-frequency noise which accompanies the useful signal and the low-frequency noise acting on the circuit of the multiplier, one obtains the following expression for the voltage at the input of an ideal (noiseless) multiplier:

$$U_{1\Sigma} = U_1(t)\cos\{\omega_0 t + \varphi(t) + m_1(t)\sin[\psi_1(t) - \varphi(t)] + k_1 U_{nr_1}(t)\}. \tag{4}$$

Since all noise sources are now accounted for, the multiplication process may be reduced to a nonlinear transformation of voltage $U_{1\Sigma}$ (4) and the separation of the (n_1)-th harmonic.

Assume that the nonlinear transformation which characterizes the multiplier is expressed by an arbitrary function $f(u)$, continuous with all derivatives in the interval $\pm u$. Obviously, the voltage at the output will have the following form:

$$\sum_{l=0}^{\infty} b_l \cos[l\omega_0 t + l\lambda(t)], \tag{5}$$

where

$$\lambda(t) = \varphi(t) + m_1(t)\sin[\psi_1(t) - \varphi(t)] + k_1 U_{nr_1}(t). \tag{6}$$

It follows that the phases of the harmonic components are simply obtained by the multiplication of the phase of the voltage U_1 by the number of the harmonic.

Therefore, the oscillation of the separated (n_1)th harmonic has the following form:

$$U_2(t) = U_2\cos[n_1\omega_0 t + n_1\lambda(t)] \tag{7}$$

or

$$\begin{aligned} U_2(t) &= U_2\cos\{n_1\omega_0 t + n_1\varphi(t) + n_1 m_1(t)\sin[\psi_1(t) - \varphi(t)] + \\ &+ n_1 k_1 U_{nr1}(t)\} = U_2\cos[n_1\omega_0 t + n_1\varphi(t) + n_1\Psi_1(t) + \\ &+ n_1 k_1 \chi_1(t)]. \end{aligned} \tag{8}$$

The obtained oscillation becomes the input signal for the next stage. After similar transformations we obtain for the output oscillation of the second multiplication stage (with the multiplication factor n_2):

$$\begin{aligned} U_3(t) = U_3\cos[&n_1 n_2\omega_0 t + n_1 n_2\varphi(t) + n_1 n_2\Psi_1(t) + n_1 n_2 k_1\chi_1(t) + \\ &+ n_2\Psi_2(t) + n_2 k_2\chi_2(t)]. \end{aligned} \tag{9}$$

Similarly, for the output oscillation of the pth multiplication stage

$$\begin{aligned} U_{p+1}(t) = U_{p+1}\cos\Big\{ & N[\omega_0 t + \varphi(t) + \Psi_1(t) + k_1\chi_1(t)] + \\ &+ \frac{N}{n_1}\left[\Psi_2(t) + k_2\chi_2(t)\right] + \frac{N}{n_1 n_2}\left[\Psi_3(t) + k_3\chi_3(t)\right] + \cdots \\ &+ \frac{N}{n_1 n_2 \ldots n_{p-1}}\left[\Psi_p(t) + k_p\chi_p(t)\right]\Big\}, \end{aligned} \tag{10}$$

where

$$\Psi_i(t) = m_i(t)\sin[\psi_i(t) - \varphi(t)],$$
$$\chi_i(t) = U_{nr_1}(t), \quad N = n_1 n_2 \ldots n_p$$

is the common multiplication factor, and $k_i = d\varphi_1 / dU_g$.

Since the statistics of all quantities in (10) may be assumed to be known, the final determination of the spectrum of the output oscillation does not represent any major difficulties. The spectrum of the output oscillation is given at the end of this paper.

Consider the phase of the oscillation in (10). The component $N\varphi(t) = \varphi_{out}(t)$ is governed by the diffusion law, while

$$\overline{\Delta\varphi^2_{out}} = N^2\overline{[\Delta\varphi(t)]^2} = N^2D\tau \tag{11}$$

where D is the coefficient of the phase diffusion, and τ is the time for which $\overline{\Delta\varphi^2_{out}}$ is defined.

Then: $D_{out} = N^2D$.

Since $D = 2\pi\Delta F$, where ΔF is the natural width of the spectral line at the level 0.5 [3], the natural width of the spectral line at the output of the multiplier $\Delta F_{out} = N^2\Delta F$.

Therefore, the natural widening (due to an ideal multiplication) is proportional to the square of the multiplication factor N^2, and its relative magnitude is proportional to N (see also [6]).

In [3], the relative magnitude of the natural width of the spectral line of the generator is estimated as $\sim 10^{-15}$-10^{-10}. As a result of the multiplication by 10^5, the relative width will be of the order of 10^{-10}-10^{-5}, which corresponds to 1-10^5 cps. The consecutive terms of the phase of the voltage $U_{p+1}(t)$ determine the phase modulation, while the band of the modulation frequencies is of the order of hundreds and thousands of cycles per second. Therefore, the phase modulation is relatively uniform in a wide band of frequencies, without any abnormal values around the center frequency (which was verified experimentally). It is true that because of the flicker effect in the region of low frequencies one may expect increased modulation indices.

Equation (10) allows us to evaluate the frequency error introduced by the multipliers.

First we shall determine the nature of the frequency error at the input of the multiplier.

$$\Delta f_{\tau\,in} = \sqrt{\overline{\Delta f^2_\tau}} = \frac{\sqrt{\overline{\Delta\varphi^2_\tau}}}{2\pi\tau} = \frac{\sqrt{D\tau}}{2\pi\tau} = \tag{12}$$

$$= \frac{1}{2\pi}\sqrt{\frac{D}{\tau}} = \sqrt{\frac{\Delta F}{2\pi\tau}},$$

since $D = 2\pi\Delta F$, where $\Delta f_{\tau\,in}$ is the mean square value of the natural frequency error at the time τ at the input of the multiplier. At the output, in the case of ideal multipliers, the relative frequency error has the same value, since

$$\Delta f_{\tau\,out} = \sqrt{\overline{\Delta f^2_{\tau\,out}}} = \frac{1}{2\pi}\sqrt{\frac{\overline{N^2D}}{\tau}} = N\Delta f_{\tau\,in}$$

The frequency error introduced by the multiplication channel is defined as $\sqrt{\overline{\Delta f^2}} = \Delta f_\tau = \frac{\sqrt{\overline{\Delta\varphi^2_{mu}}}}{2\pi\tau}$

(the error introduced by the noise of the input of the multiplier is conditionally included in the error introduced by the multipliers). All the terms in (10) which determine the phase of the output oscillation, starting with the third, represent incidental and uncorrelated magnitudes, because of which the mean square value of the increment of the incidental phase, equal to the sum of these terms, is determined as a double sum of mean squares of all terms, i.e.,

$$\overline{\Delta\varphi^2_{mu}} \simeq 2N^2\left[\overline{\Psi_1^2} + k_1^2\,\overline{\chi_1^2} + \frac{\overline{\Psi_2^2} + k_2^2\,\overline{\chi_2^2}}{n_1^2} + \frac{\overline{\Psi_3^2} + k_3^2\,\overline{\chi_3^2}}{(n_1n_2)^2} + \ldots\right.$$

$$\left. + \frac{\overline{\Psi_p^2} + k_p^2\,\overline{\chi_p^2}}{(n_1n_2\ldots n_{p-1})^2}\right], \tag{13}$$

Moreover, (13) is valid for time intervals τ considerably exceeding the correlation time of the noise voltages, which is of interest in the majority of practical cases.

In cases in which it is necessary to calculate the value of the instability in a time interval of the order of the correlation time, or shorter, one can use the foregoing expressions, which take into account the noise of the first stage.

Let us evaluate the frequency error introduced by the channel of the multiplier described in [2].

We shall note that the quantity $\frac{\overline{\Psi_i^2}}{(n_1 n_2 \ldots n_{i-1})^2}$ decreases approximately as $\frac{\overline{\Psi_1^2}}{n_1 n_2 \ldots n_{i-1}}$, since $\overline{\Psi_1^2}$ is proportional to Δf_{1-1}, and in the final account approximately proportional to $n_1 n_2 \ldots n_{i-1}$ (approximately, because the increase of the quality factor with increase of frequency, which is compensated by the current increase in the last stages, was not taken into consideration); the quantity $\frac{k_i^2 \overline{\chi_i^2}}{(n_1 n_2 \ldots n_{i-1})^2}$ decreases approximately as $\frac{k_1^2 \overline{\chi_1^2}}{n_1 n_2 \ldots n_{i-1})^{3/2}}$ because for the multiplier under consideration $k_i \simeq k_1 \sqrt[4]{n_1 n_2 \ldots n_{i-1}}$ following the increase of the quality factor of the circuit with the frequency.

In this way, according to (13) and the following remarks, we have

$$\overline{\Delta\varphi_{mu}^2} \simeq 2 \cdot 10^{10} \left[\overline{\Psi_1^2} \left(1 + \frac{1}{5} + \frac{1}{25} + \ldots\right) + 0.14^2 \overline{\chi_1^2} \left(1 + \frac{1}{11} + \frac{1}{125} + \ldots\right)\right] \simeq 2 \cdot 10^{10} \left(1{,}2\,\overline{\Psi_1^2} + 0{,}03\,\overline{\chi_1^2}\right) \tag{14}$$

(From the curve $\varphi = \varphi(U_g)$ in Fig. 7 of [2] we found the value $k_1 = 0.14$). The calculation of $\overline{\Psi_1^2}$ was referred to the grid of the preceeding (amplifying) stage, designed around the tube 6N7 with the triodes connected in parallel ($U_g = 0.1$ v).

As a result of these calculations, considering the noise characteristics of the tube at low and high frequencies [4, 5], we obtain $\overline{U_{ns_1}^2} \simeq 2.2 \cdot 10^{-12}$ v^2 with $\Delta f_{eff} = 4$ kc;

$$\overline{\chi_1^2} \simeq 3 \cdot 10^{-9} \text{ при } \Delta f_{ef} = 30 \text{ kc}\ ;\ \overline{\Psi_1^2} \simeq 10^{-10}$$

The following table gives the calculated values of the natural error and the error introduced by the multipliers.

τ [sec]	1	100	10000
$\frac{\Delta f}{f}$ nat	$10^{-8} - 10^{-10}$	$10^{-9} - 10^{-11}$	$10^{-10} - 10^{-12}$
$\frac{\Delta f}{f}$ mit	$0.3 \cdot 10^{-10}$	$0.3 \cdot 10^{-12}$	$0.3 \cdot 10^{-14}$

The error introduced by the multipliers decreases as $1/\tau$, the natural error as $1/\sqrt{\tau}$, which explains the rapid decrease of the first.

Assuming that the noise of only the first multiplication stage is important, we can obtain the following expression for the oscillation spectrum at the output of the frequency multiplier:

$$S(\omega^1) \simeq \frac{U_{out}^2}{2\pi} e^{-\left(N^2 k^2 \sigma_r^2 + N^2 \frac{\sigma_s^2}{U_{in}^2}\right)} \left\{ \frac{\frac{D_1}{2}}{\frac{D_1}{2} + (\omega_0^1 - \omega^1)^2} + \frac{\frac{D_1}{2} + \alpha}{\left(\frac{D_1}{2} + \alpha\right)^2 + (\omega_0^1 - \omega^1)^2} \cdot N^2 k^2 \sigma_r^2 + \right.$$

$$+ \frac{\frac{D_1}{2} + \beta}{\left(\frac{D_1}{2} + \beta\right)^2 + (\omega_0^1 - \omega^1)^2} \cdot N^2 \frac{\sigma_s^2}{U_{in}^2} + \frac{1}{2} \left[\frac{\frac{D_1}{2} + 2\alpha}{\left(\frac{D_1}{2} + 2\alpha\right)^2 + (\omega_0^1 - \omega^1)^2} (N^2 k^2 \sigma_r^2)^2 + \right. \tag{15}$$

(more)

$$+\frac{\left(\frac{D_1}{2}+\alpha+\beta\right)2N^4k^2\sigma_r^2\ \sigma_s^2}{\left(\frac{D_1}{2}+\alpha+\beta\right)^2+(\omega_0^1-\omega^1)^2}+\frac{\frac{D_1}{2}+2\beta}{\left(\frac{D_1}{2}+2\beta\right)^2+(\omega_0^1-\omega^1)^2}\left(\frac{N^2\sigma_s^2}{U_{\text{fn}}^2}\right)^2\Bigg]\Bigg\} \qquad (15)$$

(continued)

where

$$D_1=D_{\text{out}};\qquad \alpha=\frac{1}{R_KC_K};\qquad \sigma_n^2=\overline{U_{\text{nr}}^2};\qquad \sigma_s^2=\overline{U_{\text{ns}}^2};\qquad \beta=\frac{\omega_0}{Q};$$

Q is the quality factor of the preceding stage, and $\omega_0^1 = N\omega_0$.

The analysis of the obtained expression, considering real magnitudes, has shown that the fluctuation processes in a multiplier can greatly influence the half-width of the spectral line, in cases in which the width of the noise band is of the same order as the natural width of the spectral line at the output of an ideal multiplier.

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THE MEASUREMENT OF FREQUENCY BANDWIDTH RADIATED BY RADIO-TELEGRAPH TRANSMITTERS

M. S. Gurevich

The bandwidth occupied by the radiation of a transmitter is defined as the band of frequencies which contains 99% of the radiated power and which includes any discrete harmonic with no less than 0.25% of the total radiated power [1].

In this article, the methods of measurement of radiation bandwith are considered and some results of measurements are given.

At present three basic methods are used for radiation bandwidth measurements of frequencies below 30 Mc [2].

The first method consists of a complete analysis of the transmitted spectrum, achieved by the application of the superheterodyne principle, through the change (automatically or by hand) of frequency of each spectrum component to the same frequency, namely, that of a narrow band filter with fixed frequency characteristics. In Fig. 1 is shown, as an example, the block diagram of the spectrum analyzer used by the author for the measurement of radiation bandwidths while conducting the present investigation.

The spectrum analyzer is a device with repetition sweep at sonic frequency in which use is made of the heterodyne principle to analyze the frequency components and their levels. The frequency components are displayed on the screen of an electron-beam tube as verticle deflections ("pips") ranged on the horizontal axis in order of their frequencies. The height of the deflection is the measure of the value of the component it represents. By the use of a cathode tube with long persistence, the continuous spectrum of frequencies is obtained

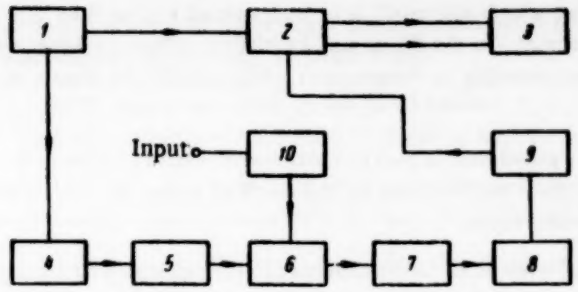


Fig. 1. 1) Sweep generator; 2) deflection amplifiers; 3) electron-beam tube; 4) reactor; 5) 100 kc generator; 6) balanced modulator; 7) filter with variable bandwidth; 8) 100 kc amplifier; 9) demodulator; 10) input amplifier and calibrator.

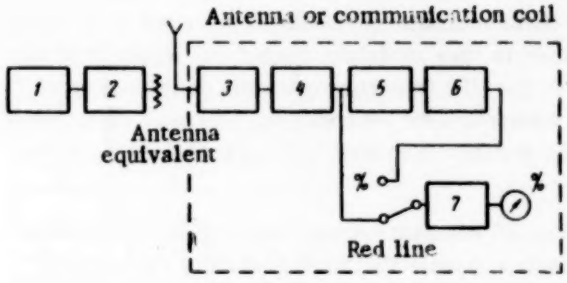


Fig. 2. 1) Generator of square dots; 2) transmitter; 3) output voltage regulator; 4) linear detector; 5) filter; 6) amplifier; 7)square-law voltmeter.

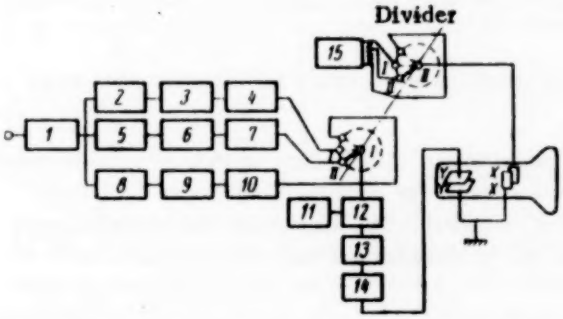


Fig. 3. 1) Input amplifier; 2) first filter; 3) first rectifier; 4) storage capacitor; 5) second filter; 6) second rectifier; 7) second storage capacitor; 8) twenty-seventh filter; 9) twenty-seventh rectifier; 10) twenty-seventh storage capacitor; 11) 3000 cps generator; 12) modulator; 13) band filter; 14) rectifier; 15) source of constant voltage.

on the screen. The output of the sweep generator is connected to the horizontal amplifier (X axis) and to the reactor which is used to change the frequency of the signal obtained from the local generator. One of the several windings of the reactor constitutes part of the bridge circuit having in one of its arms the tube of the sweep generator. To this winding is applied the saw-toothed voltage which makes possible the change of frequency range. The saw-toothed voltage amplitude is set by manual control. To the second winding of the reactor is applied the dc voltage whose variations between certain values determine the working point on the magnetization curve of the core material, thus ensuring the frequency change linearity of the local generator.

The signal from a variable-frequency local generator and the signal under investigation are fed to the balanced modulator, so that in the output of the balanced modulator the difference of frequencies (low side band) of 100 kc appears.

For separation of frequency components of the signal a filter with variable bandwidth is included after the balanced modulator. After the amplification to the required level, the 100 kc signal is rectified and, in the form of a direct-current pulse, is fed to the vertical-deflection amplifier (Y axis).

For the quantitative analysis an internal calibrator is incorporated in the device. It consists of the 1000 cps sine-wave generator and the circuit which changes a sinusoidal voltage to a sequence of square pulses of a certain amplitude.

The second method of measuring the radiation bandwidth consists of direct measurement, to determine the relative power of radiation outside the band, of that part of energy which is contained in frequency components remote from the central frequency.

The frequency components of the rectified signal are separated by an hf filter with variable cut-off frequency.

In Fig. 2 is shown the block diagram of the circuit for measuring, by the second method, the bandwidth occupied by amplitude-modulated signals. This method was published by the representatives of Japan at the I and XI Assembly of the research commission of the International Consultation Committee of Radiocommunications (ICCR), Brussels, 1955. The transmission is dot modulated. The antenna equivalent is connected to the input of the device. The input signal passes through the regulator of the input voltage and the linear detector. If the change-over switch is put in the "red line" position, the indicator shows the total voltage power on the detector. The indicator reading corresponding to "red line" is adjusted by means of the input voltage regulator and also by changing the coupling between the transmitter and the device and afterwards is kept constant. Next, the change-over switch is put in

the "%" position. Now the part of the detector power output which corresponds to frequencies higher than the cut-off frequency of the filter reaches the measuring instrument via the filter and amplifier. Thus, in addition to the measurement of total radiated power, the power corresponding to frequencies lying outside the limits of a fixed band is also measured.

The measuring instrument which has a linear scale is graudated in power units corresponding to frequencies lying within a given band. As such a measuring instrument we may use an indicator of mean values, which permits direct power measurements, ignoring the voltage wave form.

The drawback of the device described, if the speed of work is to be considered, is the necessity to change filters.

The third method consists of dividing the spectrum of frequencies into narrow bands of approximately 100 cps,each narrow band having its own narrow band filter; the output of each one of the filters is connected either permanently to a separate measuring instrument or automatically, in turn, to a common one.

The principle of action of the device is explained in Fig. 3.

The voltage under investigation is fed through an amplifier to 27 parallel-connected narrow band filters which cover the frequency range from 40 to 16,000 cps. The output voltages of the filters are applied via rectifiers, to storage capacitors and, in turn, pass to the modulator where they modulate the voltage of the 3000 cps generator and are so changed to alternating voltages. Owing to this, the frequency spectrum on the screen of oscilloscope is displayed as lines of different height, which is convenient for observation. The band filter tuned to 3000 cps stops the interfering harmonics. The purpose of the rectifier is to limit the vertical deflections on the screen to positive values.

The ganged switches I and II are motor-driven. The "jumpy" constant voltage from the voltage divider is applied to the horizontal plates of the cathode-ray tube in such a manner that each particular value of the voltage on the horizontal deflecting plates (X axis) corresponds to the connection of the tube to a particular filter. Thus, the audio frequency voltages corresponding to separate filters are shown by a row of vertical lines of varying length situated on horizontal axis. Every line is repeated approximately 20 times a second and, therefore, owing to the persistence of vision, we observe a steady picture of the frequency spectrum.

This method is mainly applicable in the investigation of nonperiodic signals, such as signals of the radiotelephony.

In accordance with ICCR recommendations, the following precision is necessary for measuring the bandwidth.

Periodic signals of class A1 (telegraphy with amplitude modulation). For the first method of measurement the laboratory equipment should be used together with automatic sweep. For work with laboratory equipment the signal under investigation must show amplitude and frequency stability. The amplitudes are measured with the aid of an attenuator calibrated relative to a constant level; the frequencies are measured by means of a frequency meter.

With sufficient amplitude and frequency stability, the precision of measurements depends only on the precision of attenuator and frequency meter. In measuring the amplitude, our error of no more than ± 1% can be attained, while in practice an error of ± 5% may be tolerated.

If the automatic sweep is used for amplitude measurement then, for low velocity of the frequency sweep, the high discrimination of the filter can be fully used and the amplitudes of frequency components situated close to the carrier frequency can be measured with precision up to ± 2db, while the amplitudes of remote frequency components can be measured with less precision, especially if narrow band filters and low transmission speed are used.

The precision of frequency swing measurement depends on the linearity of the sweep and on the width of the band under investigation. However, in the case of periodic signals the difference in frequencies of the components is usually known if the transmission speed is known.

The degree of precision of the equipment to be used in the second method of measurement depends on the desired degree of precision in measuring the power ratio and on the required steepness of the attenuation

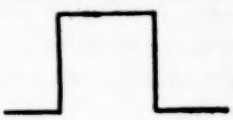
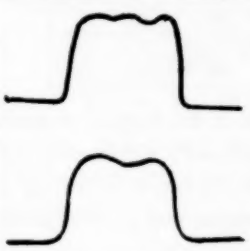
curve of the hf filter. The error in the power ratio measurement is about ±0.1%. The errors introduced by filters depend on the type of filter used.

With equipment used in the third method it is possible to secure a degree of precision of the order ±1% if the frequencies of components correspond approximately to the mean frequencies of the filters.

Periodic signals of class F1 (telegraphy with frequency modulation). The same degree of precision can be attained in the measurement of class F1 and class A1 signal spectra.

According to ICCR recommendations, the equipment used for the spectra analysis of class A1 transmitters working on medium- and shortwave bands must have the following characteristics.

The Level at the Edge of the Frequency Band Containing 99% of the Radiated Power (Amplitude Modulation)

Signal form	Level below nonmanipulated carrier, corresp. to freq. band width
	−36,4 db
	from −34 to − 30 db
	from −30 to −25 db

The bandwidth of the filter is determined in accordance with the characteristics of the signal investigated. It must be narrow in comparison to the bandwidth of the measured spectrum. Although at present one cannot give a definite preferred value of bandwidth, it is desirable that the value for static conditions should not exceed 25 cps. The frequency attenuation characteristic of the filter must have steep slopes for attenuation levels of the order 60 db.

The sweep velocity must be sufficiently slow for the curve of filter response to approach, if possible, the curve of its static characteristic. The permissible value of sweep velocity depends mainly on the bandwidth of analyzing filter.

For example, for a filter with bandwidth of 10 cps, the permissible sweep velocity is normally less than 100 cps.

The region of measured frequencies must comprise the remote spectrum components which it is desirable to measure. It seems that the maximum sweep frequency of 30 kc is enough. For the analysis of narrow band transmissions the sweep frequency must be decreased to 1 kc.

The equipment must provide the facilities for measuring components with amplitude difference of at least 60 db. It is possible to measure separately the components of high and low amplitudes, with the aid of a calibrated attenuator or a calibrated scale on the screen of an oscilloscope.

The frequency stability of generators which are part of the circuit must be such that the total frequency drift during the time of measurement is small in comparison with the effective resolving power of the filter.

In cases when the measurements are conducted according to the first method, for the determination of actual values of radiation bandwidth it is necessary to know the numerical values of levels at the edge of the frequency band containing 99% of the radiated power. In the table are shown the values of corresponding levels in cases of amplitude modulation.

In Fig. 4 is shown the relation between the modulation index and the bandwidth occupied by the transmission frequency modulated by periodic signals of square shape.

In Fig. 5 is shown the relation between the frequency modulation index and the level at the edge of the frequency band containing 99% of the power radiated by the transmission frequency modulated by signals of square shape.

The purpose of measuring the radiation bandwidth of radio telegraph transmitters was:

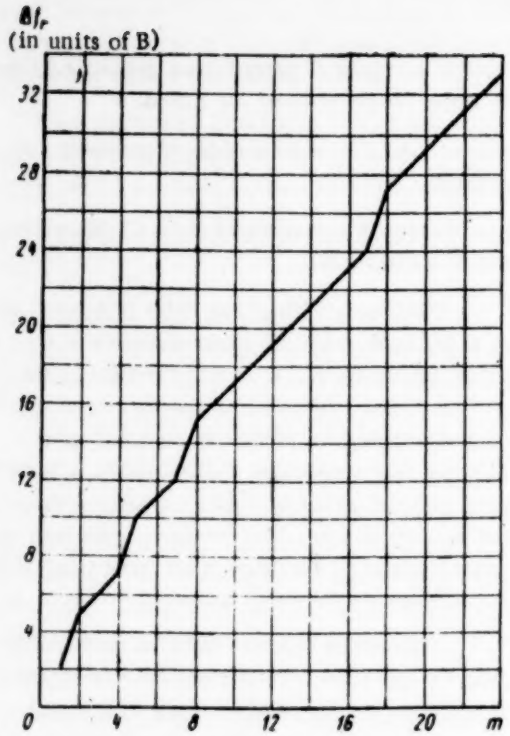


Fig. 4. B is the keying speed in bands, m = 2D/B is the modulation index, D is the frequency deviation, Δf_r is the bandwidth occupied by the frequency-modulated transmission.

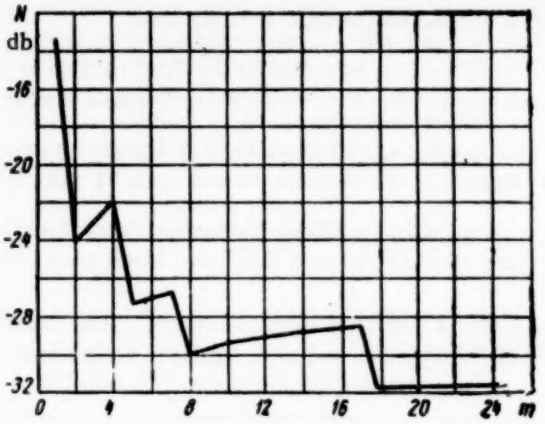


Fig. 5. $N_{db} = 10 \log_{10} n_1^2$, n_1 is the extreme component of the frequency band containing 99% of the radiated power, D is the frequency deviation, B is the keying speed in bands, m = 20D/B is the modulation index. The level is calculated in reference to the level of the unmodulated carrier, n_1 is found from the expression:

$$\frac{4}{\pi^2}\left\{\frac{1}{m^2}\sin\frac{m\pi}{2}+2m^2\sum_{n=1}^{n_1}\left[\sin\frac{(n+m)\frac{\pi}{2}}{n^2-m^2}\right]^2\right\}>\frac{0{,}99}{2}.$$

1) the determination of the degree of precision attainable by the application of the first method to the measurement of bandwidth under operating conditions of a transmitting center and control point;

2) the comparison of the results of radiation bandwidth measurements conducted under conditions of fading in the immediate vicinity of the transmitter and at the control point;

3) the accumulation of the experience in measuring the radiation bandwidth by the first method.

The measurements were carried out on the bandwidth occupied by class A1 and F1 radiations by sending square dots with speeds of 47, 97, 141, 188 and 282 bands.

For the work with the amplitude and frequency-modulated signals, a 20 kw transmitter situated in the transmitting center was used.

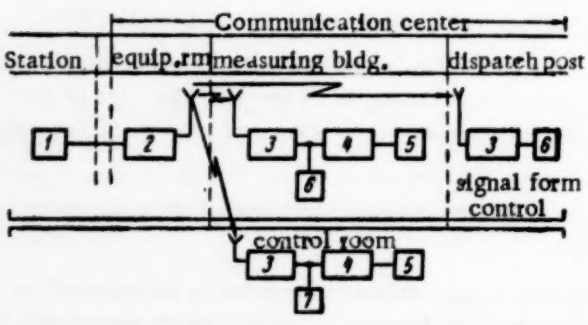


Fig. 6. 1) Signal simulator; 2) transmitter; 3) receivers; 4) spectra analyzers; 5) photo unit; 6) oscillographs; 7) signal shape control.

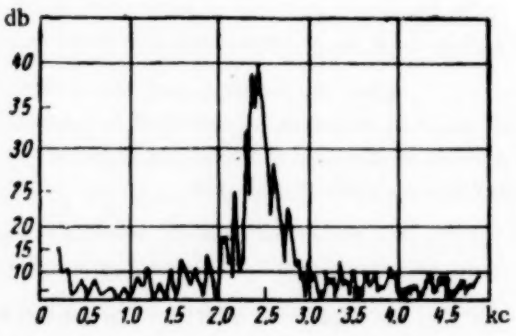


Fig. 7. Amplitude modulation (A1); square dots; keying speed 141 bands.

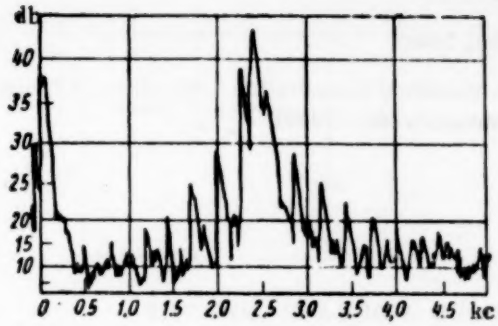


Fig. 8. Amplitude modulation (A1); square dots; keying speed 282 bands.

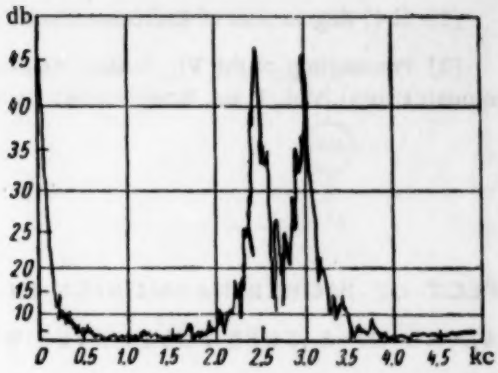


Fig. 9. Frequency modulation (F1); frequency separation 500 cps; square dots; keying speed 47 bands.

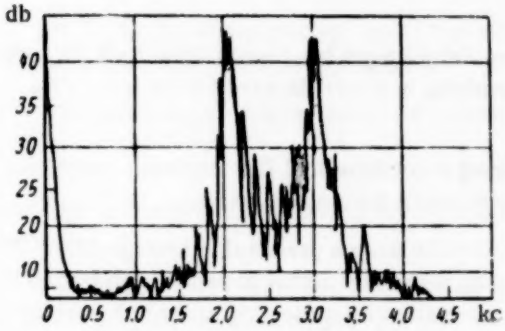


Fig. 10. Frequency modulation (F1); frequencies separation 1000 cps; square dots; keying speed 141 bands.

The bandwidth measurements were carried out according to the first method. The keying was effected from the operating room. The measurements of bandwidth and the photographing of the spectra were conducted at the transmitting center and the control point. The control of the signal shape was carried out from time at the dispatching office of the transmitting center and at the control room (recording by a loop oscillograph). In Fig. 6 is shown the block diagram of the measuring equipment. The comparison of the measurement results carried out at the transmitting center and at the control point has shown that out of 20 results of simultaneous measurements four were identical, eight differed by not more than 10%, and the disagreement between the rest of the results was still higher. In Figs. 7 to 10 are shown spectrograms obtained at the transmitting center.

As the measurements have shown, the adopted method, while effective for the measurements in the vicinity of the transmitter, can hardly be applied under conditions of fading, since under such conditions satisfactory precision of measurement cannot be achieved. Even for the measurements performed close to the transmitter the precautions are necessary in order to maintain and control the constancy of the level.

The present work has shown also that the first method of measurement, although it permits us to determine the radiation bandwidth experimentally, nevertheless is not exempt from substantial drawbacks: a) the equipment is rather complicated and requires careful handling; b) in order to avoid a shift in the frequency scale, the local variable-frequency generator must have the high degree of stability; c) at all points of the measuring scheme a careful maintenance of levels is necessary; d) all kinds of interferences considerably lower the precision of measurements; e) the suitable time interval for the execution of spectrum analysis is difficult to determine; to fix the time required for the analysis at more than 20-30 sec is not desirable, since during that time changes in conditions can take place, while if shorter time intervals are adopted and an analyzing filter with narrow enough band is used, it is difficult to get rid of the influence of the sweep velocity on the results of instrument readings, which affects the precision of measurements; f) the method does not permit the direct reading of the value of the radiation bandwidth determined in accordance with regulations of radio communications, i.e., the band of frequencies which contains 99% of the radiated power. For the determination of this value it is necessary to know the shape of the signal and the corresponding level at the edge of frequency band containing 99% of the radiated power, and then, on the basis of the calculated level, to measure the width of the band. The determination of the exact relation between the shape of the signal and the level at the edge of radiation is difficult in practice and that complicates the measurements and lowers the precision.

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[1] 1947 Regulations of Radiocommunications (Sviaz'isdat, 1949).

[2] Proceedings of the VII General Assembly of ICCR (International Consultation Committee of Radiocommunications), Vol. 1, ed. International Union of Electrocommunications (1953).

EFFECT OF HIGHER HARMONICS IN THE MEASURED VOLTAGE ON THE READING OF A TUBE VOLTMETER WITH AN EXPONENTIAL CHARACTERISTIC

M. M. Levin

The behavior of tube voltmeters when measuring nonsinusoidal voltages has been studied by B. E. Rabinovich [1], M. A. Zemel'man [2], and N. N. Solov'ev [3]; these authors, however, limited themselves to the examination of a given type of curve.

The object of this paper is to evaluate the error of measuring a nonsinusoidal first harmonic amplitude with any type of distortion, providing its shape does not differ very much from a sine wave.

This problem can be of interest in the following cases: in establishing a permissible voltage curve distortion when calibrating or checking tube voltmeters; in evaluating a standard signal generator calibration level measuring error caused by nonlinear distortion in the generator; in evaluating measuring errors due to relatively small higher harmonics when measuring "practically sinusoidal" voltages on tube voltmeters.

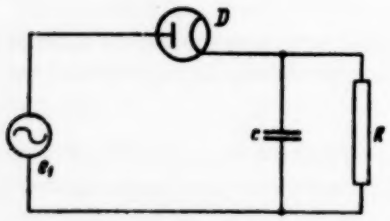

Fig. 1

The behavior of tube voltmeters when measuring voltages differing considerably from sinusoidal ones, such as, for instance, pulse voltages, will not be dealt with in this paper.

In order to make the treatment generally applicable, the measured voltage will be represented in the form of a Fourier series.

At negative voltages, the volt-ampere characteristic of diodes used in tube voltmeters is normally represented by an exponential function

$$i = Ae^{ku}, \qquad (1)$$

Moreover, for the majority of diodes, k = 8 to 12 [5].

In voltmeters used for measuring voltage amplitudes, the diodes work with high resistance loads. Hence, the voltage across the diode remains negative during almost the entire period of the measured voltage, which means that the diode works on the exponential part of the volt-ampere characteristic.

Since in a tube voltmeter, the voltage across the diode load is the basic measured quantity, the effect of higher harmonics on this voltage will be considered henceforth.

In order to analyze the diode circuit under the effect of small amplitude higher harmonics, let us employ the general method of evaluating small changes in electrical circuits [6]. According to this method, a diode current due to a harmonic is determined as the effect of the harmonic voltage in the diode differential conductance circuit, which for the small higher harmonic voltage can be considered linear. The diode differential conductance g_i is determined by the first harmonic voltage and is therefore a function of time $g_i(t)$.

Let us examine a tube voltmeter detector circuit (Fig. 1) under the effect of the first harmonic only. In the detector circuit there is an electromotive force

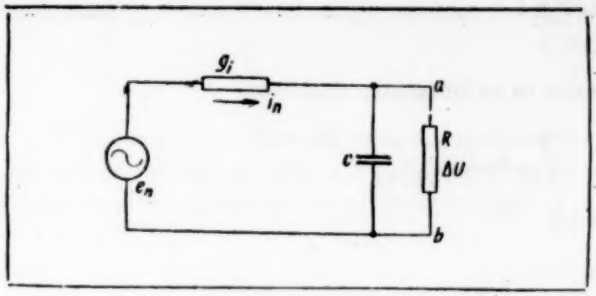

Fig. 2

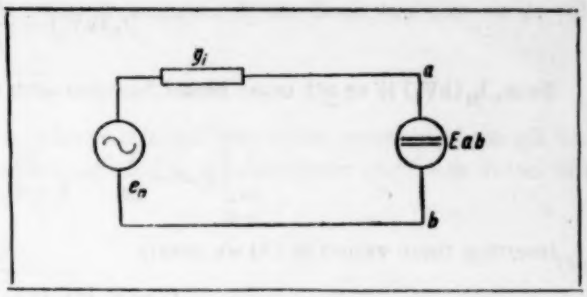

Fig. 3

$$e_1 = V_1 \cos\tau ,$$

where $\tau = \omega t$.

Let $U_=$ be the direct voltage across the diode load R (the capacity of C is large enough to make the alternating voltage across the load negligible).

It is shown in [4] that the rectified current through the diode with a characteristic shown in (1) is equal to:

$$I = Ae^{-kU} = I_0(kV_1), \tag{2}$$

where $I_0(kV_1)$ is a Bessel function of the zero order with respect to an imaginary argument, A and k are parameters in (1).

The differential conductance of a diode is the derivative of the diode current with respect to the voltage. Taking (2) into account, we obtain

$$g_i = \frac{\partial i}{\partial U} = \frac{\kappa I}{I_0(\kappa V_1)} e^{\kappa V_1 \cos\tau} \tag{3}$$

In order to find the current due to the nth harmonic, let us replace the diode by its equivalent conductance g_i (t) and consider that in the circuit (Fig. 2) there operates only the emf of the nth harmonic equal to:

$$e_n = V_n \cos(n\tau + \varphi_n).$$

Let us denote by i_n the current due to the nth harmonic and by I_n the direct component of current i_n.

According to the compensation theorem, resistance R between points a and b can be replaced by an emf:

$$E_{ab} = -\Delta U_n = -I_n R.$$

Current i_n can be represented as the effect of two emf's, e_n and E_{ab} on conductance g_i (Fig. 3):

$$i_n = e_n g_i - I_n R g_i. \tag{4}$$

The mean value of this current is equal to:

$$I_n = \frac{1}{2\pi}\int_{-\pi}^{\pi} e_n g_i d\tau - \frac{1}{2\pi} I_n R \int_{-\pi}^{\pi} g_i d\tau, \tag{5}$$

but

$$\frac{1}{2\pi}\int_{-\pi}^{\pi} e_n g_i d\tau = \frac{1}{2\pi}\int_{-\pi}^{\pi} V_n \cos(n\tau + \varphi_n) \frac{I\kappa}{I_0(\kappa V_1)} e^{\kappa V_1 \cos\tau} d\tau = \frac{I\kappa}{I_0(\kappa V_1)} V_n \left\{ \frac{1}{2\pi}\int_{-\pi}^{\pi} e^{\kappa V_1 \cos\tau} \cos n\tau \cos\varphi_n d\tau - \right.$$

$$\left. - \frac{1}{2\pi}\int_{-\pi}^{\pi} e^{\kappa V_1 \cos\tau} \sin n\tau \sin\varphi_n d\tau \right\} = \frac{I\kappa V_n}{I_0(\kappa V_1)} [I_n(\kappa V_1)\cos\varphi_n - 0] = I\kappa V_n f_n(\kappa V_1)\cos\varphi_n.$$

where

$$f_n(\kappa V_1) = \frac{I_n(\kappa V_1)}{I_0(\kappa V_1)}.$$

Here, $I_n(kV_1)$ is an nth order Bessel function with respect to an imaginary argument,

$$\frac{1}{2\pi}\int_{-\pi}^{\pi} g_1 d\tau = \frac{1}{2\pi} \cdot \frac{I\kappa}{I_0(\kappa V_1)} \int_{-\pi}^{\pi} e^{\kappa V_1 \cos\tau} d\tau = I\kappa.$$

Inserting these values in (5) we obtain

$$I_n = V_n I\kappa f_n(\kappa V_1)\cos\varphi_n - I_n R I\kappa,$$

whereby

$$I_n = \frac{V_n I\kappa f_n(\kappa V_1)\cos\varphi_n}{1 + I\kappa R},$$

and the load voltage due to the nth harmonic

$$\Delta U_n = I_n R = V_n f_n(\kappa V_1)\cos\varphi_n \frac{\kappa U_-}{1+\kappa U_-}. \tag{6}$$

where $U_- = IR$.

Denoting $V_n / V_1 = b_n$, we obtain

$$\Delta U_n = b_n V_1 f_n(\kappa V_1)\cos\varphi_n \frac{\kappa U_-}{1+\kappa U_-}. \tag{7}$$

Taking the linearity of the detector for higher harmonics into consideration, we can write, for the case of a simultaneous operation of n harmonics:

$$\Delta U = V_1 \frac{\kappa U_-}{1+\kappa U_-} \sum_{p=2}^{n} b_p f_p(\kappa V_1)\cos\varphi_p. \tag{8}$$

If the harmonic phases are unknown, we can say that:

$$|\Delta U| < V_1 \frac{\kappa U_-}{1+\kappa U_-} \sum_{p=2}^{n} b_p f_p(\kappa V_1). \tag{9}$$

When (6), (7), (8), and (9) are used, kU_- must be determined as a function of V_1. The following relation holds between kU_- and kV_1:

$$\kappa U_- e^{\kappa U_-} = A\kappa R I_0(\kappa V_1), \tag{10}$$

which follows directly from (2). Since functions xe^x and $I_0(x)$ are of a standard form, Eq. (10) can be solved with respect to kU_- with the required accuracy.

Calculations show that quantity ΔU_n is affected but little by parameter AkR. A hundred-fold change in AkR causes a change of 20% in ΔU_n at $kV_1 = 5$, and of 1.5% at $kV_1 = 20$ (for diode 2D1S, AkR = 100 corresponds to $R \simeq 1$ meg).

Experimental checks have shown that when only the second or third harmonics affect the circuit, expressions, (6) and (7) are accurate within 20% at $V_1 = 0.5$ to 100 v, $b_2 = 30\%$ or $b_3 = 20\%$ and $R > 300$ Kohm. A 2D1S diode was used in the experiment. With loads below 300 Kohm diode 2DkS works off the exponential part of its characteristic.

The error of (6) and (7) with other type diodes will be of the same order providing that

$$\frac{R_l}{R_{i0}} > 30-50.$$

where R_Σ is the sum of all the active resistances connected in series with the diode, including the internal resistance of the measured voltage source, and R_{io} is the internal resistance of the diode at a zero anode voltage:

$$R_{io} = \frac{1}{Ak}.$$

In order to evaluate the error of measuring the first harmonic amplitude in the presence of the nth harmonic, let us find the change ΔV_1 in the reading of the voltmeter graduated in first harmonic amplitude values brought about by a change ΔU in the rectified voltage:

$$\Delta V_1 = \frac{\partial V_1}{\partial U_-}\Delta U. \tag{11}$$

Since V_1 cannot be expressed in terms of $U_=$, overtly it becomes expedient to represent (10) in the form

$$I_0(\kappa V_1) = \frac{\kappa U_- e^{\kappa U_-}}{A\kappa R} \tag{12}$$

According to the rules of differentiating functions in an overt form, we obtain

$$\Delta V_1 = \frac{1}{\kappa \dfrac{\partial I_0(\kappa V_1)}{\partial(\kappa V_1)}} \cdot \frac{\partial I_0(\kappa V_1)}{\partial U_-}\Delta U. \tag{13}$$

By inserting (12) into (13) we obtain, after transformation,

$$\Delta V_1 = \frac{1+\kappa U_-}{\kappa U_-} \cdot \frac{I_0(\kappa V_1)}{I_1(\kappa V_1)}\Delta U. \tag{14}$$

By inserting the expression for ΔU, obtained from (7) into (14), we obtain, after transformation, the relative measuring error of the first harmonic amplitude:

$$\frac{\Delta V_1}{V_1} = b_n \frac{I_n(\kappa V_1)}{I_1(\kappa V_1)}\cos\varphi_n \tag{15}$$

or

$$\left|\frac{\Delta V_1}{V_1}\right| < b_n \frac{I_n(\kappa V_1)}{I_1(\kappa V_1)}. \tag{16}$$

By using approximation formulas for Bessel functions, we obtain

$$\frac{\Delta V_1}{V_1} = b_n \frac{(\kappa V_1)^{n-1}}{2^{n-1}n!}\cos\varphi_n \qquad \text{at } \kappa V_1 < 2, \tag{17}$$

$$\frac{\Delta V_1}{V_1} = b_n \frac{8\kappa V_1 - 4n^2 + 1}{8\kappa V_1 - 3}\cos\varphi_n \quad \text{at } \kappa V_1 > 10. \tag{18}$$

For intermediate values of kV_1 we found it impossible to suggest convenient approximation formulas.

Inspection of (15), (17), and (18) shows that the relative error $\Delta V_1/V_1$ increases with kV_1 and tends to $b_n \cos\varphi_n$.

Fig. 4 shows the relationship between $I_2(kV_1)/I_1(kV_1)$ and $I_3(kV_1)/I_1(kV_1)$ and the quantity kV_1.

For a simultaneous action of n harmonics, we obtain, according to (8) and (9):

$$\frac{\Delta V_1}{V_1} = \frac{\sum_{p=2}^{n} b_p I_p(\kappa V_1)\cos\varphi_p}{I_1(\kappa V_1)}. \tag{19}$$

or

$$\left|\frac{\Delta V_1}{V_1}\right| < \frac{\sum_{p=2}^{n} b_p I_p(\kappa V_1)}{I_1(\kappa V_1)}. \tag{20}$$

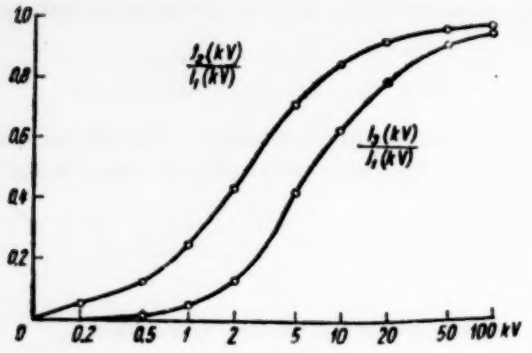

Fig. 4

It will be seen from (15), (19), and Fig. 4 that the voltmeter approaches an amplitude measuring device with a rise in the measured voltage, since as k increases, V_1 [$\ln(kV_1)/I_1(kV_1)$] tends to unity.

Let us now evaluate the error of measuring the effective voltage in the presence of harmonics.

The effective voltage with a small coefficient of nonlinear distortion is equal to:

$$V_\partial = V_1\left(1+\frac{\gamma^2}{2}\right). \tag{21}$$

where γ is the nonlinear distortion coefficient. On the other hand, the voltmeter reading according to (19) is equal to

$$V=V_1\left[1+\frac{\Sigma b_n I_n(\kappa V_1)\cos\varphi_n}{I_1(\kappa V_1)}\right]. \tag{22}$$

whereby the absolute error in measuring the effective voltage is equal to

$$V-V_\partial=V_1\left[\frac{\Sigma b_n I_n(\kappa V_1)\cos\varphi_n}{I_1(\kappa V_1)}-\frac{\gamma^2}{2}\right].$$

By neglecting value $\gamma^2/2$, which is small compared with unity, it is possible to write the expression for the relative error in measuring effective voltage as:

$$\frac{V-V_\partial}{V_\partial}=\frac{\Sigma b_n I_n(\kappa V_1)\cos\varphi_n}{I_1(\kappa V_1)}-\frac{\gamma^2}{2}. \tag{23}$$

If the harmonic phases are not known, it is possible to indicate the limits within which the error lies:

$$\frac{\Sigma b_n I_n(\kappa V_1)}{I_1(\kappa V_1)}-\frac{\gamma^2}{2}<\frac{V-V_\partial}{V_\partial}<\frac{\Sigma b_n I_n(\kappa V_1)}{I_1(\kappa V_1)}-\frac{\gamma^2}{2} \tag{24}$$

With a rise in (kV_1) the error limits extend and (24) tends to the form

$$-\Sigma b_n-\frac{\gamma^2}{2}<\frac{V-V_\partial}{V_\partial}<\Sigma b_n-\frac{\gamma^2}{2}. \tag{25}$$

For an experimental verification of (6) and (7), voltage $u = V_1\cos\omega t + V_n\cos(n\omega + \Omega)t$ was impressed on the diode. It was found that voltage Δu_n was not direct but varied according to the cosine law with a frequency Ω. Inspection of the shape of voltage Δu_n registered on a recording instrument showed the correctness of expressions (6) and (7) at any values of φ.

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ELECTRODYNAMIC AMMETER FOR MEASURING HIGH-FREQUENCY CURRENTS

V. L. Lopan'

In the course of developing high-frequency reference measuring instruments, the All-Union Scientific Research Institute for Physical and Radiotechnical Measurements designed an electrodynamic ammeter for measuring currents of 5 to 100 amps in the frequency range of 1 to 100 Mc.

The present paper describes the principle of operation and the constructional details of this ammeter and analyzes its faults.

The Principles of Operation of the Electrodynamic Ammeter (Fig. 1).

The measured current i_1 flows in the primary circuit 1, establishing round it an electromagnetic field. A short circuited turn 2 is suspended in this field. If turn 2 is placed in such a position that it links with the magnetic lines of force of circuit 1, a current i_2 will be induced in it. Between currents i_1 and i_2 there will arise pondermotive interacting forces, which will tend to rotate turn 2 about its suspension in the direction of least coupling with circuit 1. Torque M acting on turn 2 can be expressed by the formula:

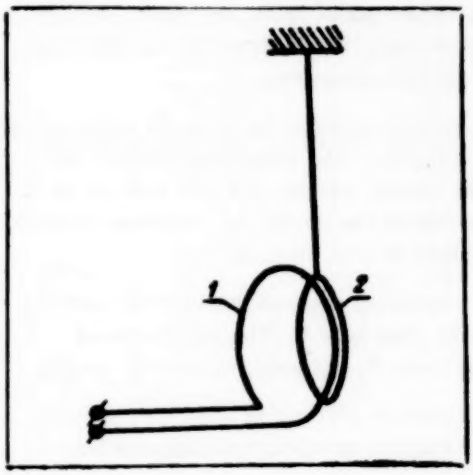

Fig. 1

$$M = I_1^2 \frac{L_{12}}{L_2} \cdot \frac{\partial L_{12}}{\partial \Theta} (1-\gamma)^2, \quad (1)$$

where I_1 is the effective value of the measured current, L_2 is the self-inductance of turn 2, L_{12} is the mutual inductance of circuit 1 and turn 2, Θ is the deviation angle of turn 2 from the minimum coupling with circuit 1, $\gamma = R/L_2$, R is the active resistance of turn 2, and ω is the measured frequency.

The electrodynamic VNIIFTRI ammeter measures the interacting forces on the basis of the pendulum principle.

This principle consists in the following. Turn 2 is suspended in the field of circuit 1 by a thin thread which does not exert any elastic resistance. Under the action of torque M, turn 2 will take up a definite position, corresponding to the minimum coupling and hence the minimum potential energy of the system. If the turn is given a definite deflection by turning it through angle Θ with respect to the minimum coupling position, it will return to this position after a number of damped oscillations.

The oscillations are caused on one hand by the restoring force and on the other by the effect of coil inertia.

The equation of these oscillations, without taking into account the friction or elasticity of the suspension thread, has the form:

$$\frac{d^2\Theta}{dt^2} + \frac{I_1^2}{JL_2} L_{12} \frac{\partial L_{12}}{\partial \Theta} (1-\gamma^2) = 0. \quad (2)$$

where J is the moment of inertia of the turn.

The turn oscillation period T and current I_1 flowing in circuit 1 are related by the expression

$$I_1 = \frac{C}{T}, \quad (3)$$

where C is the instrument constant.

Thus the measurement of the high-frequency current is reduced to measuring the period of oscillations and determining the instrument constant C.

The instrument constant C can be calculated from the geometrical dimensions of the system and the mass of turn 2. Thus, the electrodynamic ammeter can be considered an absolute instrument in which current measurements are reduced to measuring length L, mass M, and time T.

On the other hand, constant C can be determined experimentally by comparing the electrodynamic with a thermal ammeter at 1 to 5 Mc.

Constructional Details of the Electrodynamic Ammeter (Fig. 2)

The current carrying part of the instrument is made of a twin coaxial line 1.

The length of the line is 200 mm, internal conductor diameter 2-12 mm, external cylinder diameter 3-80 mm. The internal conductor is fixed by polystyrene washers 4.

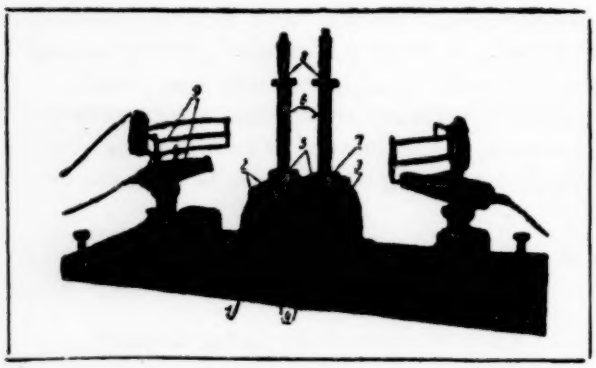

Fig. 2

The electrodynamic ammeter vibrating turn is made in the shape of a 20 mm diameter ring of a round conductor. The diameter of the conductor is 0.5 mm. The ring is made of aluminum, copper, or gold for the ranges of 5-15, 15-50, and 50-100 amps, respectively. Slot 5 serves to pass the ring along the coaxial conductors.

The ring is suspended by a quartz thread which also holds a mirror. The suspension between the ring and the mirror is made of a stiff wire 30-40 μ in diameter; above the mirror the suspension consists of a thin thread 3-10 μ in diameter.

The suspension is protected from air currents by an organic glass tube 6. The ring is moved horizontally by means of carriage 7, vertically by means of micrometer screw 8, and about its axis by turning the suspension thread at its fixing point.

The period of ring oscillations is determined automatically by means of a special stopwatch counter.

Figure 2 shows the optical system 9 of the counting device. The electronic part of the counter is mounted in a separate unit.

Determination of the Instrument Constant C

According to expressions given in [1], and taking into consideration that in the system "coaxial line-ring" under consideration, angle Θ is small, expression (2) can be written in the form:

$$\frac{d^2\Theta}{dt^2}+\frac{\mu_0^2\, a^4 I_1^2\,(1-\gamma^2)}{4\,h^2\,JL_2}\left[\Theta+\Theta^3\left(\frac{a^2}{h^2}-\frac{2}{3}\right)\right]=0, \tag{4}$$

where a is the ring radius, h is the distance of the center of the ring from the coaxial line axis, and μ_0 is the permeability in vacuum.

The oscillations represented by (4) are nearly sinusoidal, since the term containing Θ^3 is small.

According to a method described in [2], we can obtain from (4) an expression for the period of oscillations with an accuracy up to Θ_0^2 where Θ_0 is the amplitude of oscillations:

$$T=\frac{2\pi}{I_1\sqrt{\frac{\mu_0^2 a^4(1-\gamma^2)}{4h^2\,JL_2}\left[1+\Theta_0^2\left(\frac{3}{4}\cdot\frac{a^2}{h^2}-\frac{1}{2}\right)\right]}} \tag{5}$$

Whereby, according to (3), we obtain an expression for the instrument constant C:

$$C=\frac{2\pi}{\sqrt{\frac{\mu_0^2 a^4(1-\gamma^2)}{4h^2JL_2}\left[1+\Theta_0^2\left(\frac{3}{4}\cdot\frac{a^2}{h^2}-\frac{1}{2}\right)\right]}} \tag{6}$$

Quantities L_2, γ, and Θ_0 are not constant. L_2 and γ change with frequency, producing a frequency error of $\Delta C_f/C$.

The amplitude of the ring oscillations changes due to the damped nature of the oscillations:

$$\Theta_0=e^{-\frac{\delta t}{T}}\Theta_{0\ \max}, \tag{7}$$

where t is the measuring time, δ is the logarithmic damping ratio, and $\Theta_{0\max}$ is the maximum aplitude of oscillations.

Since Θ_0 is usually small, it is possible to neglect the term in (6) which contains Θ_0^2 and to consider (3) to be linear, allowing at the same time for a certain nonlinearity error $\Delta C_\Theta/C$

An expression for the frequency error $\Delta C_f/C$ is obtained from (6) by using the formula for the self-induction of the ring [3]; at any frequency:

$$L_2=\mu_0 a\left(\ln\frac{16a}{d}-2+\eta\right) \tag{8}$$

and the approximate expression for the self-induction at an infinitely high frequency,

$$L_\infty=\mu_0 a\left(\ln\frac{16a}{d}-2\right), \tag{8a}$$

where

$$\eta=\frac{\xi}{4}=f\left(\frac{d}{2}\sqrt{\frac{\omega}{\rho}}\right),$$

ρ is the resistivity of the ring material, and d the diameter of the ring conductor; ξ for nonmagnetic materials is determined from Tables 2-1 [3].

With a rising frequency parameters η and γ decrease to zero.

Thus the error $\Delta C_f/C$ at an infinitely high frequency is equal to zero.

At any frequency

$$\frac{\Delta C_f}{C}=\sqrt{\frac{\ln\frac{16a}{d}-2+\eta}{\left(\ln\frac{16a}{d}-2\right)\cdot\left(1-\gamma^2\right)}}-1\simeq$$
$$\simeq\frac{1}{2}\cdot\frac{\eta}{\ln\frac{16a}{d}-2}-\frac{1}{4}\gamma^2. \tag{9}$$

The expression for error $\Delta C_\Theta/C$ is obtained from (6) taking (7) into consideration

$$\frac{\Delta C_\Theta}{C}=e^{\frac{-2\delta t}{T}}\Theta_{0\max}^2\left(\frac{3}{8}\cdot\frac{a^2}{h^2}-\frac{1}{4}\right). \tag{10}$$

The elasticity of the suspension thread has not been taken into account in (4). This holds for thin threads and large currents, but for measurements at the lower limit it may become necessary to take the elasticity into account.

The error due to the elasticity of the thread in determining constant C is calculated from the formula

$$\frac{\Delta C_y}{C} = \sqrt{1-\left(\frac{T}{T_0}\right)^2}-1, \tag{11}$$

where T_0 is the easily determined experimentally natural period of oscillations of the ring in the absence of any current.

If the systematic errors obtained from (9), (10), and (11) are corrected, the remaining error $\Delta C_u/C$ will not exceed, in the most unfavorable case, ± 0.2% for each error. If errors (9) and (10) are corrected, expression (6) will assume a convenient form for calculations

$$C = \frac{4\pi h}{\mu_0 a^2}\sqrt{L_\infty J}. \tag{12}$$

The self-induction of the ring L_∞ at an infinite frequency can be obtained with any degree of accuracy from the formula given in [4]. The screening effect on L_∞ of the external cylinder of the coaxial lead is negligible due to its large diameter and the smallness of L_∞, and it can be neglected.

The moment of inertia of the ring is determined from formula

$$J = \frac{1}{2} m\left(a_b^2 + \frac{5}{16}d^2\right), \tag{13}$$

where m is the mass of the ring obtained by weighing on analytical scales, and a_b is the ring radius.

The formula for the error $\Delta C_M/C$, due to the inaccuracy of determining the mechanical and geometrical parameters in calculating C, is obtained from (12), (13), and (8a), taking into consideration the random character of the errors in determining these parameters:

$$\frac{\Delta C_M}{C} = \sqrt{\left(\frac{\Delta h}{h}\right)^2 + \left(\frac{1}{2}\right)^2\cdot\left(\frac{\Delta m}{m}\right)^2 + \left[\frac{1}{2\left(\ln\frac{16a}{d}-2\right)}+\frac{1}{2}\right]^2\left(\frac{\Delta a}{a}\right)^2 + \left[\frac{1}{2\left(\ln\frac{16a}{d}-2\right)}\right]^2\cdot\left(\frac{\Delta r}{r}\right)^2}. \tag{14}$$

The total error of calculating C is determined by the formula

$$\frac{\Delta C}{C} = \sqrt{3\left(\frac{\Delta C_u}{C}\right)^2 + \left(\frac{\Delta C_M}{C}\right)^2}. \tag{15}$$

The experimental determination of C is carried out by calibration of the electrodynamic ammeter at a low working frequency against a thermal or photo-ammeter. The latter are in turn calibrated against a standard ammeter at 50 cps.

In determining C experimentally, errors $\Delta C_\Theta/C$ and $\Delta C_M/C$ do not arise, and errors $\Delta C_f/C$ and $\Delta C_y/C$ have to be corrected by calculation.

The total error in determining C experimentally is evaluated at 0.6%. Comparison of the values of C obtained by calculation and experimentally at the low end of the scale showed a discrepancy of less than 1%.

Error in Determining the Period of Ring Oscillations

The above error consists of the counting device error and the damping error.

The counting device error is evaluated at ± 0.1%.

The error due to the damping of ring oscillations is calculated from formula

$$\frac{\Delta T_3}{T} = -\frac{1}{2}\left(\frac{\delta}{2\pi}\right). \tag{16}$$

In the most unfavorable condition when $\delta = 0.25$, this error is equal to $\Delta T_3/T = 0.05\%$, and it can be neglected.

Designation of errors	Limits of measurement, a			Data on which calculations were based
	5–15	15–50	50–1000	
$\Delta T/T$	0,1%	0,1%	0,1%	
$\Delta C_f/C$	2,5%	1,4%	1,8%	f – 1 Mc
$\Delta C_\theta/C$	–0,3%	–0,3%	–0,3%	$\theta_e max$=15°, δ–0,25, h–20 мм
$\Delta C_m/C$	±0,68%	±0,48%	±0,48%	Δh–0,04 мм, Δa–0,03 мм Δd–0,02 мм, Δm–0,1 мг
$\Delta C_y/C$	–0,9%	–	–	T–2,7 sec, T_0–20 sec
$\Delta C_p/C$	±0,6%	–	–	
3σ	±0,5%	±0,3%	±0,3%	
Total error $\frac{\Delta I}{I}$	0,9%	0,68%	0,68%	

Error Due to Current Distribution

The ring of the electrodynamic ammeter and the ammeter being checked are at a certain distance l from each other. The presence of a current standing wave will cause an error whose value will depend on the frequency of measurement, distance l, and the input impedance of the measured instrument, which is usually inductive. The error due to the current distribution is determined by formula:

$$\frac{\Delta I_v}{I} = \frac{\cos 2\pi \frac{l+l_e}{\lambda}}{\cos 2\pi \frac{l_e}{\lambda}} - 1, \qquad (17)$$

where l_e is the length of the electrodynamic ammeter line, equivalent to inductance L_a of the ammeter being checked, λ is the wavelength, and l_e is obtained from expression

$$l_e = \frac{\lambda}{2\pi} \operatorname{arctg} \frac{\omega L_a}{z_0}, \qquad (18)$$

where z_0 is the impedance of the twin coaxial ammeter line.

By placing the ring at various distances l along the axis of the coaxial line at a constant current, l_e can also be determined experimentally.

The error caused by the current standing wave can be neglected up to 100 Mc (at l = 35 mm) when checking thermoammeters.

Random Error

The mean square random error σ of the electrodynamic ammeter, which indicates the consistancy of its reading, can be determined by repeated measuring of the same current. When required precautions, which exclude gross errors, are observed, the random error of the electrodynamic ammeter at the low range (5 amp) does not exceed the value σ = 0.2% and for currents above 15 amp σ = 0.1%. Thus, when checking it is sufficient to measure the same current five times.

The electrodynamic ammeter underwent thorough experimental investigation. Results of comparing the electrodynamic ammeter with a standard photoammeter with radial cells is particularly interesting. The difference in readings of the electrodynamic and the photoammeter in the lower range of 5 amp at 1, 25, 50, and 100 Mc, with the systematic errors corrected, did not exceed the limits of a random error.

The values of the above errors of the electrodynamic ammeter are given in the table.

The total error was calculated on the assumption that the systematic errors had been corrected. The uncorrected remainders of the systematic errors and the random error were added according to the law of adding random errors.

It follows from the table that the error of measurement of an electrodynamic ammeter lies within 1%.

The described ammeter will be used for government testing and checking of ammeters at high frequencies.

It has been used for testing T-12, T-4, and T-5 thermoammeters and for investigating frequency errors in high-frequency current transformers.

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REVIEWS AND ESSAYS

MODERN AUTOMATIC ELECTRONIC POTENTIOMETERS AND BRIDGES

M. A. Zemel'man

The circuits and layout of modern electronic automatic instruments are developing in two directions. On the one hand, theoretically old circuits and layouts are being improved and supplemented in order to raise the technical and working characteristics of the instruments and extend their sphere of application. On the other hand, completely new, original circuits are being developed, based on the use of recently developed materials and methods of transformation, balancing, etc.

The most common improvement of the normal potentiometer circuit is the use in its measuring circuit of stabilized rectifiers which, during a long time, maintain an effective current with a required accuracy. In such cases the instrument can be worked completely from the ac supply. The dry cell and sometimes the standard cell are thus eliminated, making the operation of the instrument considerably simpler: there is no longer any need to check regularly the working current to inspect the condition of the dry cell and change it periodically.

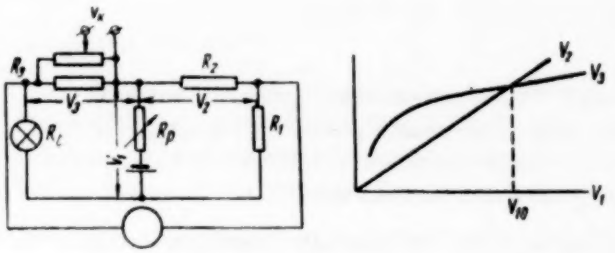

Fig. 1

Stabilizers used for this purpose are different in principle from the normal voltage stabilizers. As distinct from the latter type, the new stabilizers must not only smooth out short disturbances and variations in the supply voltage, but must also maintain the output voltage (current) at a required value with a desired accuracy (not less than 0.1-0.2%) during a considerable time. The widely used normal gas-filled tube stabilizers are unsuitable for this purpose.

Information is available of several types of stabilizers developed for feeding measuring circuits of potentiometers. Some of the instruments use stabilizers in principle similar to the normal type, but operating with a standard cell as the source of reference voltage, instead of the normal gas-filled tube. The use of drift-free amplifiers with such stabilizers provides an error in the voltage not exceeding 0.05-0.1%.

There exist stabilizers even without the standard cell. As an example, bridge stabilizers with a nonlinear arm can be cited. The principle of operation of such a stabilizer can be gathered from Fig. 1. An incandescent lamp R_l can be used as a nonlinear element. Variations of the supply voltage V_1 affect V_2 and V_3 in the way shown in the graph of Fig. 1. When $V_1 = V_{10}$, the bridge is balanced and V_3 has quite a definite value. Voltage V_{10} can be maintained by automatically changing R_p when the bridge becomes unbalanced. Thus, the working current of the potentiometer measuring circuit is set by the bridge balance. Voltage V_3 is used as a compensating voltage, since it changes little with variations in V_1. The accuracy of the stabilized voltage is determined by the stability of the resistances R_1, R_2 and R_3, and the characteristic of the nonlinear element. Experience has shown that the stability of some of the incandescent lamps is completely adequate for practical purposes. It should be noted that such a stabilizer does not smooth out momentary voltage bursts since it has a certain degree of sluggishness. By means of this bridge a working current can be maintained with an accuracy of 0.15%.

Automatic potentiometers with their measuring circuits fed from the ac supply are made by a number of foreign firms, for instance Bristol (USA), Foster (Britain), and others.

The Institute of Automation and Remote Control of the Academy of Sciences, USSR, has produced and tested out a sample of a so-called ferroionic stabilizer. These stabilizers use for their reference voltage a gas discharge tube which, however, works under unusual conditions: the voltage across the tube contains not only a dc but also a considerable ac component which, according to the designers of the stabilizer, very considerably decreases the instability of the voltage across the tube. Although the ferroionic stabilizer was developed precisely for feeding the measuring circuits of automatic potentiometers, it has not yet been adopted industrially and we have no automatic potentiometers fed from the ac supply.

An important tendency in perfecting automatic potentiometers and bridges is the raising of their sensitivity and accuracy. The highest sensitivity of mass-produced instruments in the USSR is 10 mv and, by special order, 5 mv. The permissible error is 0.5% of full scale. Abroad, many types of instruments are produced with a higher sensitivity and greater accuracy.

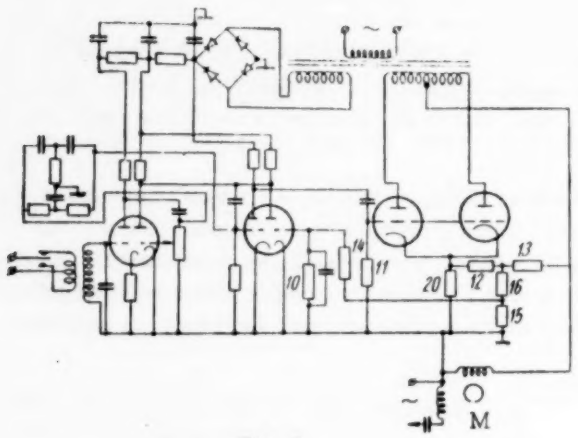

Fig. 2

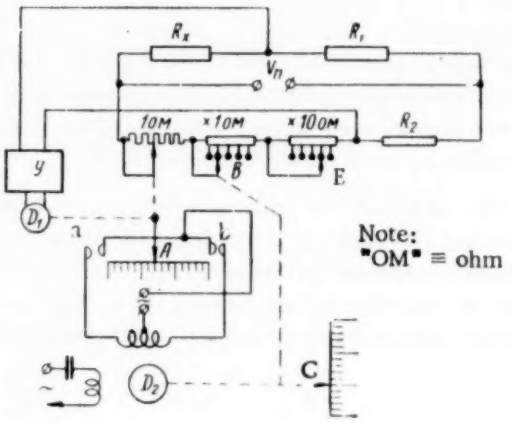

Fig. 3

As an example, the following instruments can be cited: "Microvolt-Maltelec Recorder," made by the Kent Co. (Britain), with a sensitivity of 100 μv; the Sunvic (Britain) automatic potentiometer measuring down to 0.5 mv; the "Electronic" recording system of the Honeywell Brown Instrument Co. (USA), measuring down to 100 μv; the "Elnick" set of Ions and Co. (F.G.R.), measuring down to 2 mv, and others.

As examples of accurate instruments, the following can be cited: the automatic potentiometer made by Philips (Holland) with an accuracy of 0.25%; the automatic potentiometer and bridge of the Thermo-Electric Co. (USA) with an accuracy of 0.25%, automatic potentiometer and bridge of the Pyrometrie Industrielle (France), accuracy 0.2%; the automatic potentiometer of the Aser firm (Britain), with an accuracy of 0.1%,and others. In the last-but-one instrument,for improved accuracy of reading a part of the scale is amplified 5 times and projected with the pointer onto a screen.

A potentiometer measuring up to 200 μv (with a sensitivity of 1 μv) has been developed and made in the USSR, but it is not designed for mass production.

In modern instruments the speed of operation is increased by introducing negative feedback or special differentiating circuits in the amplifiers.

For increasing the damping of the system negative feedback related to the speed of the motor is applied. With this object in view, special tachometer generators mounted on a common axis with the motor are used; the emf produced by them is then fed into the amplifier circuit.

Another example of the application of feedback related to the speed of the motor is given in Fig. 2, which shows the circuit of the Soviet-made potentiometer amplifier PS. In this circuit, the negative feedback related to the motor speed is attained by means of resistances R_{12}, R_{13}, R_{14}, R_{15}, and R_{16}, and the right-hand side of the second triode. When the motor is stationary there is no 50 cps voltage on its controlling winding. The rotation of the motor induces a voltage in the controlling winding proportional to the speed of rotation. By means of the

above resistances,a signal proportional to the voltage is impressed on the tube grid, is amplified and fed to the grid of the third amplifier stage applying a negative feedback related to the motor speed. The response time of PS instruments of various types is not less than one second. Abroad, instruments are made with a smaller delay time. For instance, in the already-mentioned "Electronic" system, the response time does not exceed 0.5 sec; the AIL instrument, type 373A (The Precision Engineering Keston Manufacturing, USA), the response time does not exceed 0.25 sec.

In normal automatic potentiometers and bridges the minimum error of measurement is determined by the accuracy of reading. With a normal graph paper width limited by the size of the instrument, the reading cannot be recorded more accurately than 0.1-0.2% of the paper width. An increase in accuracy with a given size,or the extension of the measurement range without lowering the accuracy,can be attained by increasing the paper width. Several sets have been developed recently whose scale is of the same size as in normal instruments, but is used several times over, recording the last significant figures instead of the whole reading.

The principal of operation of such instruments becomes clear from Fig. 3, which shows as an example an automatic bridge. Its slide wire has a resistance of 1 ohm. Its slider is rigidly connected with pen A driven by motor D_1 when the bridge is unbalanced. When pen A approaches one of its extreme positions, contact a or b is closed (depending in which extreme position the pen happens to be), causing motor D_2 to turn in the appropriate direction. Motor D_2 is connected to switch B and pen C. Switch B changes the bridge arm resistance in steps of 1 ohm. The contacts of switch B and switch E are placed on a circle. When the wipers of switch B reach one of its extreme positions, the wipers of switch E move one step in the corresponding direction; simultaneously wiper B is moved to the opposite extreme, and then continues its movement in the previous direction due to the continued excitation of motor D_2. The angle through which motor D_2 has turned and,hence,the position of pen C corresponds to the total resistance set up by switches B and E (units and tenths of ohms). The position of pen A corresponds to tenths of an ohm. Thus, according to the position of pens A and C, it is possible to estimate a resistance up to 100 ohms with an accuracy of 0.001-0.002 ohms (0.1-0.2% of 1 ohm), i.e., an accuracy of 0.001-0.002%. When measuring,it is necessary to add the readings corresponding to both pens.

Such a bridge was developed for measuring temperatures in the region of −190°C to +550°C with an error not greater than 0.01°C.

Similar automatic potentiometers with an expanded scale are made by the Honeywell Brown Instrument Co. (USA), the Applied Physics Corp. (USA), and others. In this country, similar instruments have also been developed by various organizations for their own use. Information is available of tensometric bridges with expanded scales. Certain devices designed to measure voltages also work on the same principle.

One of the important modernizations of automatic potentiometers and bridges is the so-called two-coordinate recorder. In normal instruments the measured quantities are recorded as functions of time. For this purpose the recording graph paper is moved by means of a synchronous motor so that its displacement is proportional to time. In a two-coordinate recorder the displacement of the paper is not proportional to time, but to the quantity against which the measured value is plotted. Thus, the two-coordinate recorder registers plot graphs of functions type $y = f(x)$.

Such instruments are made by Honeywell Brown Instrument Co., Electro-Instruments, Inc. (USA), Phoenix Precision Instrument Co., and others.

Two-coordinate recorders are not made in the USSR.

In view of the rapid development of automation and saturation of industry with recording measuring instruments, the problem of decreasing their size has become extremely pressing. With former instrument sizes and a scale length of 275 mm,instrument chassis had to be made large, occupying a considerable space and inconvenient to operate. That is why recently there appeared several types of automatic potentiometers and bridges with the same technical characteristics as normal instruments, but of a much smaller size.

Type PS potentiometers and MS bridges have been developed in the USSR with the main technical parameters similar to the instruments type EPP and EMP, but only occupying a quarter of the area of the latter (their size being 29 × 33 × 44 cm), with a scale length of 160 mm. Westronics, Inc. (USA) has produced a miniature automatic potentiometer with a 120 mm scale. The accuracy claimed for the instrument is 0.25%, and the time required for the pointer to traverse the whole scale 0.5 sec. The instrument has no standard cell.

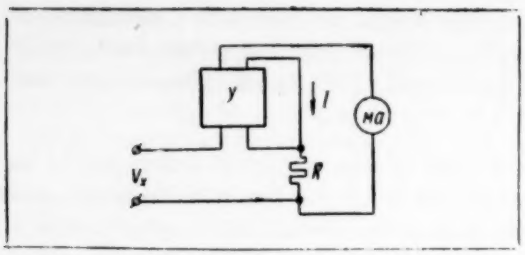

Fig. 4

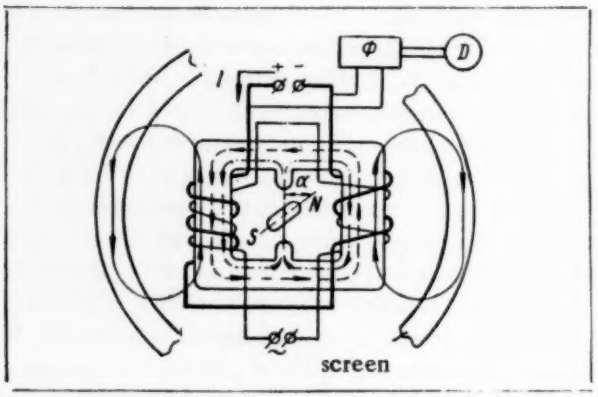

Fig. 5

The Cambridge Instrument Co. (Britain) makes an instrument with a 180 mm scale and over-all dimensions 40 × 42 × 40 cm. It measures down to 1 mv; the pointer traverses the whole scale in 2 sec; the accuracy is 0.5%. The measuring circuit can be fed either from a dry cell or from a built-in stabilizer which maintains the working current with an accuracy of 0.1% during a month or more.

Similar instruments are now being manufactured by other firms as well, but their number is as yet small.

New Principles of Operation

Side by side with the development of automatic instruments on the lines outlined above, and based on known principles of operation, instruments are now being developed on the basis of new, original principles of operation.

A few years ago there appeared the first short reports about an automatic potentiometer, developed by the General Electric Co. (USA), based on entirely new principles of converting direct to alternating current, and of measuring the compensating current. This instrument has no slide wire with a sliding contact,no dry or standard cells,and no vibrating converter.

It will be seen from the schematic of the instrument shown in Fig. 4 that the compensation of the measured current I is attained by means of resistor R. An ac voltage amplifier with a dc-to-ac current converter at its input and a phase-sensitive rectifier at its output is used as a null indicator and a source of the compensating current. The converter consists of a germanium crystalline plate in an alternating magnetic field. When a direct voltage is applied to two opposite edges of this plate, an alternating voltage arises across the other two edges (Hall's effect),whose amplitude and phase are determined by the value and sign of the applied direct voltage. The converted voltage is amplified and rectified, causing a compensating direct current I to flow through resistance R. The converter, based on Hall's effect, has one undoubted advantage over the normal vibrating converters in the fact that it does not contain any moving parts. In order to improve accuracy, the compensating current I which determines the measured voltage V_X is not measured by a normal milliammeter, but by means of a special device based on a balancing method of measuring current called "electromagnetic standard" method.

The circuit of this device is shown in Fig. 5. A fixed magnetomotive force permanent magnet which can turn about its axis is placed in the gap of a core made of nonresidual magnetic material. The magnetic flux path of the permanent magnet is closed through the core, creating in it a constant magnetic field, shown on the drawing by a dash-dot line. The core magnetic flux established by the permanent magnet is a single-valued function of the magnetomotive force and the turning angle α. The core has a winding for the compensating current I which is to be measured. This current induces a constant magnetic field in the core (full lines) in the opposite direction to the field of the permanent magnet with its path closing through the screen. The core has yet another winding fed from a half-wave rectifier,which produces in the core a pulsating field shown by a dotted line. The pulsating magnetic field produces a periodic change in the permeability of the core. If the current I flux and the permanent magnet flux do not balance out, there will remain in the core a residual constant flux. As the result of the periodic change of the permeability of the core, an alternating component is produced in the flux, which induces in the direct current winding an alternating emf which is filtered, amplified, and applied to the reversing motor. The axis of the latter is connected to that of the permanent magnet.

When the constant magnetic fluxes are not balanced in the core, the motor will turn the magnet until balance is restored. Since the magnet mmf is fixed, each value of the measured current corresponds to a quite definite position of the magnet, i.e., to a definite angle α. A pointer or a pen rigidly connected to the magnet axis indicate on a scale the value of current or directly that of the voltage V_x.

Thus, in the above potentiometer the method of automatic balancing is used twice. In the first instance the voltage V_x is balanced out by means of current I_1 in the second instance, the current I flux is balanced out by the permanent field of the magnet. The standard measure which in the main determines the accuracy of measurement is the permanent magnet whose stability can be very great. In this instance the permanent magnet replaces the standard cell which has much worse operating characteristics, such as sensitivity to overloading, or turning upside down, failure at low temperatures, etc. On the other hand, the high metrological qualities of a standard cell are hardly used in industrial potentiometers. The substitution in industrial instruments of a standard cell by a permanent magnet and of vibrating converters by a converter without moving parts presents great possibilities, all the more so, since in the above circuit the use of a slide-wire is also eliminated, whose sliding contact is a source of many difficulties in operation and, in addition, there is no need to set the measuring current any longer.

It is, however, difficult as yet to judge the expediency of the practical application of this circuit and construction to mass-produced instruments. As a matter of fact, any information on a sufficiently full investigation of the performance of such an instrument is lacking. At the same time, it is clear that for a normal operation of the instrument a high degree of symmetry of construction and uniformity of material characteristics both for the converter and the "electronic standard" are required. What is the converter's "lack of sensitivity" or the "electronic standard's" error due to the possible asymmetry of construction, how complex must be the measures ensuring the required degree of symmetry under various conditions, these are some of the technical questions which must be solved in designing such an instrument.

Reports appeared in the last few years of automatic potentiometers and bridges employing a new principle of recording readings. The readings are not indicated by a pointer on a scale, but similarly to industrial power meters, by a set of figures. The number of significant figures varies with the sensitivity and accuracy of the instrument.

In indicating instruments such digital display registration is preferable to pointer indication since the former avoids subjective errors. Moreover, the accuracy of such instruments can be considerable; instruments with 5 significant figures are already known.

In industrial instruments display figures are made large enough to provide accurate reading from considerable distances. Due to the absence of a long scale, the area occupied by these instruments on a rack can be reduced.

Another advantage of the figure display instruments is the greater ease with which the obtained reading can be made to operate a control system than would be the case with pointer instruments. This property of the above instruments makes one assume that they will find a wide application in automatic control systems.

There are two types of figure display instruments mentioned in the technical literature—those working on the static and dynamic compensation principles.

When figure display instruments are used for recording they must be made cyclic in operation. A continuous recording by means of a figure printing mechanism is not possible, it would appear.

Instruments with a figure display are made by many firms abroad.

Specialized automatic bridges with figure display and cyclic printing of numbers on paper have been developed in the USSR. So far, however, they have not been designed for mass production.

Information on instruments made by foreign firms and described above was obtained from the following journals: The Journal of Scientific Instruments, Instrument Practice, Measure, ATM, Instruments and Automation, Electronics, The Review of Scientific Instruments, and others dated 1953-1954.

In conclusion it should be noted that with respect to the variety of automatic potentiometers and bridges produced and to the application in their design of the latest achievements of instrument technology, our country is lagging behind the other technically advanced countries.

An important task for the Soviet instrument industry is the development and bringing into mass production of instruments on the lines similar to those described in this article. The proof of the urgent necessity for such instruments is the development and production in a semi-handicraft fashion of these instruments on a small scale for their own use by noninstrument-making organizations.

HILGER INTERFEROMETER FOR ABSOLUTE AND RELATIVE MEASUREMENTS OF LENGTH

I. T. Uverskii

Hilger and Watts, Ltd. (Britain) are now manufacturing a double-beam interferometer for absolute and relative measurements of plane-parallel end gauges up to 300 mm long [1]. The measuring methods used in these instruments differ from other such methods by eliminating the requirement of grinding in gauges to auxiliary plates. In all the measurements performed by these instruments, the measured surfaces of gauges are not subject to deformations due to adhesive contacts which are inevitable, for instance, in the case of absolute measurements with a Kester interferometer [2]. A schematic plan view and partial side elevation of Hilger's interferometer are given in Figs. 1a, b.

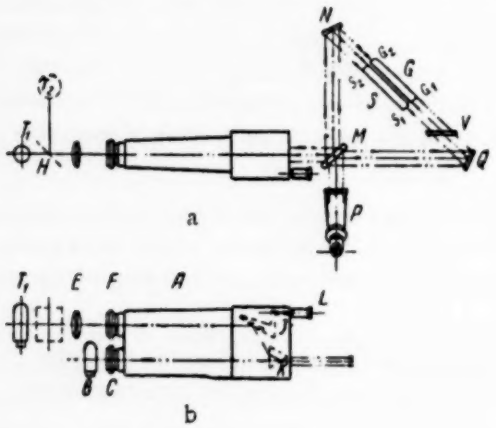

Fig. 1

The double collimator A operates either with a source of white light B placed in front of the slit C, or with a source of monochromatic light T_1 placed in front of condenser E and slit F. Source T_1 can be replaced by another source of monochromatic light T_2, which is switched in by an appropriate turn of mirror H.

The monochromatic light, having passed the collimator, is reflected from mirror I onto a diffusing prism K. The mirror is turned by means of a microscrew attached to drum L, which bears a scale specially calibrated in wavelengths. The scale is used for selecting the required monochromatic lighting of the interference chamber.

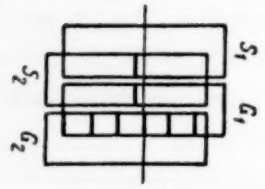

Fig. 2

If it is required to work with white light, prism K is withdrawn.

The light which enters the chamber falls on the dividing plate M. Part of the light is reflected from it onto mirror N, falls on the measuring surfaces of the gauge, and is reflected back from them onto telescope P. Another part of the light passes through to mirror Q, falls onto the opposite measuring surfaces of the same gauge, is reflected back from them and then directed by plate M onto telescope P. If the difference in the light paths from plate M is sufficiently small, interference bands will become visible in the telescope's field of vision.

Plate V is a compensator for plate M and serves to place on top of each other (overlap) the images of the measuring surfaces.

A comparison of two gauges is shown in Fig. 1a. The gauges are laid side by side and the images of all four measuring surfaces, which are partly superimposed, are observed through the telescope (in Fig. 2 the relative vertical displacement is shown conventionally; in the instrument it is not observable).

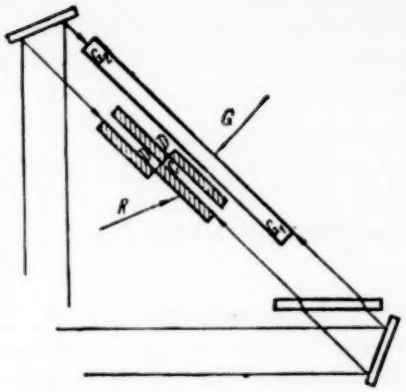

Fig. 3

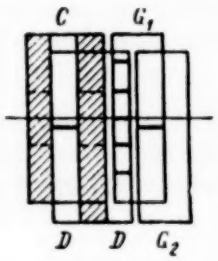

Fig. 4

The position of the standard gauge S is adjusted in such a way that its measuring surfaces become equidistant from the separating surface of plate M. Then at the overlap of S_1S_2, interference bands will appear. The position of equal optical paths will be marked by a black achromatic band; colored bands of diminishing intensity will appear on either side of this band.

The position of the measured gauge G is adjusted in such a way that its measuring surface G_1 is in a plane coinciding with that of S_1. Then a similar interference picture will be seen in white light at the overlap of G_1S_2, as in the case of S_1S_2, and the direction of similarly colored bands will also coincide.

The difference in the gauge lengths is determined by the displacement of the black achromatic line at the overlap of G_1G_2 with respect to a similar line at G_1S_2; the error of measurement according to the firm's data does not exceed ± 0.000025 mm.

The absolute measurement of a gauge is shown in Fig. 3. A special (reference) caliber R, supplied with the interferometer, is placed side by side with gauge G. The caliber consists of two parts, ground-in in such a manner that the opening of one is opposite the flat surface of the other, and vice versa. The images of the gauge surfaces G_1G_2 and those of calibers C and D, partly superimposed, are observed through the telescope (in Fig. 4 the vertical displacement is conventional similarly to Fig. 2).

The position of the gauge and the caliber are adjusted in white light so that colored interference bands appear at overlaps G_1G_2 and CD, and both black achromatic bands coincide with the longitudinal hairline of the instrument. Such an adjustment ensures accurate positioning of the middle of the ground-in layer between surfaces C and D halfway between the measuring surfaces of the gauge, whose length becomes equal to double the distance, for instance, between G_1 and D.

This distance is determined by the usual method of the coincidence of fractional parts of interference bands observable at overlap G_1D in monochromatic light of different spectral line sources T_1 and T_2 (Fig. 1). For such sources of light Hilger and Watts recommend electrodeless Hg^{198} tubes and cadmium discharge tubes. Gauges up to 150 mm can be measured over the whole length. In this case, surfaces G_1 and D are placed by means of the white light interference effect into one plane, and then observed at overlap G_1G_2 for fractional band parts in monochromatic light as required by the method described above.

As a result, the length of the gauge is measured plus a fixed grinding-in thickness introduced by caliber R.

The errors in absolute measurements of gauges, depending on their lengths are, according to the firm's data, between ± 0.000025 and ± 0.000125 mm.

These Hilger interferometers are valuable as highly accurate contactless instruments which do not wear or damage gauges in the process of measurement.

LITERATURE CITED

[1] Hilger, Absolute-Length Gauge Interferometer CT106/2 (firm's leaflet).

[2] A. N. Zakhar'evskii, Interferometers [in Russian] (Oborongiz, 1952).

INFORMATION

THE INTERNATIONAL CONSULTATIVE COMMITTEE FOR DETERMINING A SECOND

The development of modern science has led to a position when measurements of time are made with different seconds: the astronomical and the physical second. The astronomic second is a 1/86400 part of a siderial day determined from astronomical observations. As the result of the uneven rotation of the earth about its axis, the relative length of a second during a year changes by $\pm 3 \cdot 10^{-7}$. This instability of the second could not ensure accurate measurements and resulted in the introduction, with developing technique, of various physical seconds based on the application of crystal clocks, which provide a more even time scale and hence a second which changes less with time.

Such a position was abnormal from the point of view of the unity and accuracy of time measurements, and in October, 1956, the International Weights and Measures Committee established a new determination of the second as 1/31556925.9747 part of a tropical year for January 0,1900 at 12 hours by the ephemeris time. This determination of the second is based on the scale of an even ephemeris time.

For the purpose of making suggestions for the practical application and improvement in the standard of time, the International Weights and Measures Committee established the International Consultative Committee for Determining a Second (ICCS). This committee consists of an approximately even number of physicists and astronomers who represent the Scientific and Research Institutions of the majority of countries taking part in the international time service and conducting development of crystal and atomic standards of time and frequency.

The ICCS comprises several international organizations: the Bureau of Weights and Measures, the Bureau of Time, and the Astronomical Union, and national metrological organizations such as the Bureau of Standards (USA), the National Physical Laboratory (Britain), the Physico-Technical Institute (FGR), the Institute of Physico-Technical and Radio-Technical Measurements (USSR), and national astronomical institutions: the Greenwich Royal Observatory (Britain), the Naval Observatory in Washington (USA), the Institute of Theoretical Astronomy in Leningrad (USSR), and others.

The first meeting of the ICCS took place on June 3 and 4, 1957 at the International Bureau of Weights and Measures (in Sevres, Paris) under the chairmanship of Prof. Danjon. The meeting was attended by 24 representatives from 11 countries,including: Vallee, Danjon, Decot, Perrare and Stoicot (France); Brown, Clements, Markovich and Freeman (USA); Sadler, Spencer, Johnson and Essen (Britain); Burdun and Lubentsov (USSR); Boella and Silva (Italy); Frick and Shaiba (FGR); Fusch (Austria); Calra (Canada); Ort (Spain); Pendis (Yugoslavia), and Miadi (Japan).

The basic task of the meeting was the review of the existing state of investigation and practical application of molecular generators and check point standards, based on the application of molecular and atomic resonance absorption frequencies of various substances in the microwave band, as atomic frequency standards.

Representatives of various scientific institutions made brief reports on these questions, followed by a very lively discussion.

1. The successful establishment of the theory and production of experimental models of ammonia molecular generators in the Lebedev Physical Institute of the Academy of Sciences, USSR and the National Bureau of Standards (USA) led, in 1957, to the repetition of these experiments, or a close approach to their repetition, in a number of institutes in the USSR, Japan, America, Britain, FGR, and Switzerland.

In 1955, the National Physical Laboratory (Britain) developed a check point standard based on the absorption frequency of a caesium molecular beam in a magnetic field. This work,with certain alterations,was repeated in 1956-57 by the Massachusetts Institute of Technology (USA); the results of these investigations, however, are as yet unknown. At present many institutes in the USA, USSR, Italy, France, Canada, and the FGR, are producing caesium check point oscillators.

The first attempt at establishing an atomic frequency standard was made in 1949 by the National Bureau of Standards (USA) by producing its so-called "atomic" clock based on the absorption frequency of ammonia line 3-3 in a gas medium. Since then,work of this kind has been carried out in many countries, but, as it would appear, is still being pursued only in Japan. Promising results, however, have not been obtained yet with this device.

2. Comparison of the results obtained in various scientific research establishments shows that the highest frequency stability has been obtained to date by means of the caesium check point standard. The relative instability of the standard does not exceed $\pm 1 \cdot 10^{-10}$. This result has been obtained by a systematic comparison of several devices during a long time, but the frequency of individual caesium standards differs by amounts of the order of $\pm 1 \cdot 10^{-9}$. Slightly less accurate are molecular generators with their relative frequency deviation of about $\pm 1 \cdot 10^{-9}$. These generators, however, possess a number of advantages, above all being sources of fixed frequency oscillations, whereas the caesium check point standard is essentially a resonator. The disadvantage of the generators consists in their frequency being influenced by the tuning of the cavity circuit, resulting in a difference of the order of $\pm 1 \cdot 10^{-8}$ between the frequencies of individual generators.

The comparison of the caesium standard frequencies was carried out by means of the transmission of standard frequencies or special exact time signals. The relative error in comparing frequencies by radio amounts to $\pm 1 \cdot 10^{-9}$, and that due to comparing time signals during a month to about $\pm 3 \cdot 10^{-10}$, and during a year to $\pm 3 \cdot 10^{-11}$.

In discussion and the recommendations adopted by the meeting, the need for the most rapid organization of mutual international frequency checks of national atomic frequency standards was stressed. In this connection it was found necessary to develop comparison methods which would ensure a greater accuracy obtained during shorter time intervals. In connection with the attention paid to questions of comparing frequency standards and the close relation of these questions to the tasks of the International Scientific Radio Union Commisssion, it was found expedient to carry out the standard frequency comparisons under the scientific guidance of this commission; this recommendation was embodied in an appropriate resolution. The practical organization of comparisons must be carried out under the auspices of the International Bureau of Weights and Measures, which is the central metological organ.

3. The determination of the actual value of the caesium frequency check point in terms of the astronomical time according to system TU-2 was carried out by the International Bureau of Time. This determination obtained the actual value of the caesium frequency with a relative error of about $\pm 3 \cdot 10^{-10}$.

The determinations of the actual frequency of ammonia line 3-3 made in Japan and Switzerland differ by an amount of the order of $7 \cdot 10^{-8}$.

In view of the caesium check frequency possessing a greater stability with time, it is important to have a more accurate determination of the actual value of that frequency in terms of the ephemeris time obtained by observations of the moon. This important question was examined by a special sub-committee which arrived at the following conclusions: "The ICCS sub-committee studied the accuracy of the ephemeris of the moon in connection with the practical determination of the ephemeris time.

According to the evaluation, which took into consideration various errors, the present ephemeris of the moon can ensure an accuracy in determining a second of the ephemeris time over a five-year period with a relative error of about $1 \cdot 10^{-10}$.

Smaller or larger investigation intervals produce a smaller accuracy. The sub-committee notes that the planet terms in Brown's lunar theory are determined with uncertainty and that there should be a complete review of Brown's lunar theory.

The sub-committee arrived at the conclusion that a greater accuracy in determining the astronomical

time is required in order to find the actual values of the standard frequencies, and recommended to submit these findings for discussion at Commission No. 4 of the International Astronomical Union. These proposals were approved by the ICCS.

4. As the result of discussions, it was confirmed that further fundamental investigations of caesium check point standards and molecular generators was expedient. Particular attention was paid to the necessity of having in all the national metological establishments atomic frequency standards of various types for better comparative investigation purposes. It was found desirable to investigate the possibility of constructing atomic frequency standards of a different design and with different materials (thallium).

A general requirement applicable to all devices of this kind is the necessity of establishing a condition of operation under which the resonance frequency of the check point standard of the generator would correspond as closely as possible to the resonance absorption frequency of the molecules (atoms) used and be as independent as possible of the variations in the device parameters. The atomic frequency standards should be as simple as possible in order to ensure their similarity and reliability in operation when made in different establishments.

Preference should be given to atomic frequency standards in which the resonance absorption frequency is measured directly as compared with devices which have an auxiliary generator whose frequency is tuned by a servo mechanism.

With respect to the caesium check point frequency standard, it is expedient to find out the influence on frequency measurements of the homogeneity of the field in the region of the excitation of the beam, of the lack of correct phase relationships in the waveguide circuits, and of the presence of fluctuations in the intensity of the beam. It is of interest to investigate the relations between the shape of the spectrum line and such phenomena as, for instance, the presence of noise in the excitation circuits.

With respect to the ammonia molecular generators, it is necessary to investigate the relation between the frequency and the quality, construction, and tuning of the generator cavity circuit, the intensity of the beam, and the potentials of the grading electrodes. For a successful use of the molecular generators, it is necessary to work out a method of precise tuning of the cavity circuit frequency to the resonance absorption frequency of the molecules.

For the practical application of the atomic frequency standards it is now necessary to compare their frequency accurately with the frequency of crystal oscillators. In this connection it is important to investigate further the additional errors arising in frequency multiplication of the standard crystal oscillators due to the instability of the parameters and the presence of fluctuations in the multiplying circuits.

5. In connection with the proposal to adopt the caesium frequency standard of the National Physical Laboratory as an international standard of time and frequency, after detailed discussion the majority of those present arrived at the following conclusions:

a) Since at present all the devices based on the resonance absorption frequency of atoms and molecules are as yet discontinuously operating, and hence lack the possibility of counting time continuously, they cannot become time standards and are only frequency standards, and must, therefore, be called according to their method of application, "atomic frequency standards."

b) It is premature to decide on establishing a numerical value for the caesium frequency standard until sufficient data has been accumulated on similar devices in other scientific establishments and mutual investigation of various types of atomic standards has been conducted and international comparison of frequency standards is established.

ASRIM CONFERENCE ON TEMPERATURE MEASUREMENTS OF FLAMES AND GAS STREAMS

A. N. Gordov

The 1957 session of the Commission on Pyrometry of the All-Union Scientific Research Institute of Metrology discussed problems connected with measuring temperatures of flames and gas streams.

The conference was attended by representatives of 41 organizations, including 5 Institutes of the Academy of Sciences, USSR, departmental and industrial enterprises of Moscow, Leningrad, Khar'kov, Dnepropetrovsk, and others.

Sixteen papers dealing with various methods and instruments were read and discussed at the conference. The majority of papers dealt with the measurement of flame temperatures, and three papers with the measurement of gas stream temperatures. The attention of the conference was centered on noncontact (optical) methods as the best suited for investigating temperatures of flames.

Great interest was aroused by the paper read by A. E. Kadyshevich, in which he showed on the basis of calculations that,with a pronounced nonuniformity in temperature fields of torches, the utilization of the visible region of the spectrum for temperature measurements can lead to a considerable increase in the measurement results. More reliable results are obtained if investigations are made in the infrared part of the spectrum. Moreover, the most important in this respect is the radiation band around 4.3 μ.

Ia. I. Merson read a paper on the methods and instruments used for flame temperature measurements by means of radiations in the infrared region.

O. N. Dubrovskaia reported on the investigations conducted by her of the method of determining radial nonuniformity of the temperature fields in torches by means of measuring the "optical" temperature along several chords.

V. V. Kandyba described the results of investigations obtained by the method he developed for measuring flame temperatures by means of the absolute intensity of spectral lines, and reported on the possibilities of the application of this method with the help of the Fabrie and Perot standard and a resonance lamp.

A group of workers under the direction of V. K. Prokof'ev read several papers on flame temperature measurements by the distribution of intensity in the molecular band rotating structure, on the application of photographic photometric methods, and on a photoelectric instrument which can record luminosity in momentary processes.

A. L. Sviridov reported on the flame temperature variations with respect to the intensity of spectral lines in two wavelengths.

V. V. Babushkin read a paper on the measurement of rapidly changing temperatures of an open flame by colored pyrometry method,using independent simultaneous recording of the photoelectric currents of two photocells.

I. G. Sedykh briefly reviewed, in his paper, measuring methods of gas stream temperatures up to 1000°C, and the specific peculiarities and technical errors arising in the course of such measurements.

A. N. Gorodov reported on some cases of dynamic errors in measuring variable temperatures of gas streams under conditions of changing loss of heat.

The complex nature of the objects of measurement, i.e., of the torch flames and their diversity, was commented upon at the conference. It was noted that on the one hand it is necessary to study the object in every respect and, on the other, to develop many measuring methods both for the purpose of mutual checking, and due to the specific conditions of application of some of the methods. This point of view found its expression in the

conference resolutions. The desirability of developing the promising method of infrared pyrometry and the pressing need for the development of methods for measuring high gas stream temperatures up to 1000-1500°C, were also mentioned.

The conference noted the necessity of evaluating critically which were the preferable spheres of application of various methods for measuring flame temperatures and of determining the errors inherent in these methods.

The conference also noted the necessity of coordinating further investigations in the sphere of flame temperature measurements. Coordination of the schematic plans can be made by calling a more restricted conference of representatives of organizations working in the sphere of pyrometry of flames and gas streams. The organization of this conference was entrusted to the pyrometric commission of the ASRIM.

It was decided to publish the papers read at the conference as a separate collection.

CONFERENCE ON RADIOACTIVE METHODS OF CHECKING

L. G. Stolyarov

A scientific and technical conference on radioactive methods of checking and controlling production processes was called in 1957 in Riga by the Central Administration for the Utilization of Atomic Energy, attached to the Council of Ministers of the USSR, the A. S. Popov Scientific and Technical Society of Radio Technology and Telecommunications, the Council of National Economy, and the Academy of Sciences of the Latvian SSR. The conference was attended by some 500 scientists and engineers from Moscow, Leningrad, Kiev, Riga, and other cities. The conference discussed over 30 papers and reports dealing with the theory, construction, and industrial application of instruments using radioactive isotopes.

The conference noted in its resolution that one of the most important lines of development for radioactive methods of checking and controlling production processes is the theoretical investigation of these methods.

The conference noted the expediency of developing and using standard electronic instrument units and standardizing the existing instruments and those under development, and the necessity of greatly improving mutual information and exchange of experience.

V. N. MIL'SHTEIN

After a prolonged and grievous illness, Prof, Viktor Naumovich Mil'shtein, D. Sci. (Tech.), a noted specialist in the sphere of the theory and design of electrical and radio-measuring instruments, died on January 9, 1958, at the age of 44.

V. N. Mil'shtein started his scientific and teaching activity at an early age. He was responsible for over 40 printed papers and investions in the sphere of electrical- and radio-measuring technology and automation. He originated a number of investigation and design methods applied in practically all known electrical measuring and many radio-measuring instruments, including those used for measuring nonelectric quantities. As early as 1940, V. N. Mil'shtein published a paper on "Foundations of the electrical design of inductive devices for measuring small displacements," in which he proposed, for the first time, a method of designing various measuring circuits by means of equivalent circuits, and developed the power theory of measuring instruments. These ideas, developed in detail in his subsequent works, have received widespread recognition.

At the time when he was already seriously ill, V. N. Mil'shtein prepared for the printing of his book, "Power Relations in Electrical Measuring Instruments," which occupied his attention to the last days of his life.

In 1949, V. N. Mil'shtein jointed the system of the Committee for Standards, Measures and Measuring Instruments where he first worked in the MGIMIP and later in the VNIIFTRI as senior scientific officer and head of the laboratory. Here he carried out a large number of investigations dealing with the theory and development of methods for evaluating various instruments, and important work at a high scientific level in state testing of a number of instruments. He also lectured to engineers and metrologists in order to improve their qualifications. At the same time, he continued teaching first at the Penza Industrial Institute and later in the Moscow Electrotechnical Institute of Communications.

V. N. Mil'shtein took an active part in the journal, "Measuring Techniques."

V. N. Mil'shtein's scientific activity was characterized by a concrete and practical approach. He considered as his main task the creation of a basis for the solution of engineering problems and the design of instruments. This formed the basis of his creative collaboration with the personnel of many of our instrument-making enterprises.

V. N. Mil'shtein had a highly developed sense of the new, a clear understanding of the most important tendencies in the development of our national instrument-making industry, of the necessity of introducing modern scientific methods into our higher education.

He expected a very high standard of scientific work both from himself and his pupils, who valued his ever-present readiness to help and to convey his knowledge to others.

The Soviet Government highly valued V. N. Mil'shtein's achievements, rewarding him with the "Order of Merit," and other medals.

Our metrologists and instrument makers will for a long time preserve the memory of V. N. Mil'shtein, the talented scientist, teacher, kindly and helpful comrade.

MATERIAL RECEIVED BY THE EDITORIAL BOARD

COMMENTS ON B. N. VORONTSOV'S AND I. A. PANFILOV'S ARTICLE "ALLOWANCES FOR THE WEAR OF WIRES" (A Discussion)

V. N. Bortsov, deputy director of KhGIMIP, considers that the article contains erroneous conclusions which could lead in the future to unnecessary expenditure of labor and materials.

The new instruction 127-57 establishes the following scheme for testing wires: third grade end gauges; telescope caliper; wires for checking the mean thread diameter.

What are the drawbacks of this system, according to the authors of this article?

The drawbacks consist in the necessity to sort the wires out into "paired" and "single" which, according to them, greatly impedes the checking process, and in omitting a correction for the clearance error of wires in the usual estimation for the error due to the wear of wires.

Instead of this simple system, the authors propose a complicated one: third grade end gauges; telescope caliper; specially selected sets of sample wires; telescope caliper; specially selected complements of master thread-calibres; telescope caliper; specially selected sets of service wires.

This system requires: selecting, by means of third grade gauges, sets of "model" wires with minimum diameter differences and stricter requirements with respect to clearance (for each pitch); testing by means of these sample wires, a telescope caliper and a universal microscope, special master calibres with minimum pitch and profile angle deviations (also for each pitch!); testing by means of the checked master thread-calibres specially selected sets of service wires which would give a difference in instrument readings for various combinations of wires not exceeding 1 μ for first-class, and 1.5 μ for second-class wires.

If all the random errors are added in this complicated checking sequence, the total error for a set of wires in the most favorable case will be of the order of ± 1.6-1.8 μ instead of ± 0.5-0.6 μ obtainable by the existing system.

It becomes obvious that the proposed system is inexpedient when the greater expenditure of labor required by it is also taken into consideration. Let us now rever to the existing system drawbacks pointed out by the authors.

It can easily be seen that the separation of wires into "paired" and "single" is not at all obligatory. It is possible to mark off only a single wire; it is also possible to select sets of wires according to their deviation from the normal in such a way that their order becomes immaterial. Such an operation in mass checking of wires does not present any difficulties, all the more so since it is also required in the system proposed by the authors, where it must even be repeated twice.

It should be said about the remark that the calculation by means of the formula does not account for the clearance error, that this criticism also holds good with respect to the system proposed by the authors, since the wires always become wedged in the thread spiral in a random position.

Finally, for a given allowance in the wear of the wires, certain wires or entire sets will still be differentiated; this can be obtained in a simpler way by normal checking on the telescope caliper than by checking sets in various combinations on the master calibre.

L. Ya. Vyshkind, head of the TsIL factory (Leningrad), notes that the checking procedure proposed by

B. N. Vorontsov and I. A. Panfilov is not expedient since it complicates the process of measuring thread calibres.

The proposed scheme requires sets of sample wires and specially selected thread (sample) calibres.

The set of sample wires can be relatively easily selected from the 0-th class of wires, but the selection of a set of special calibres is wrought with great expenditure of labor. Moreover, the checking of thread calibres according to the proposed method will take twice as long as it would normally since, in order to establish the correction for service wires, it is first necessary to measure the mean diameter of the corresponding master calibre.

The comparative data in Table 2 of the article shows that the difference between the correction according to the formula and by means of the calibre only amounts to tenths of a micron; this quantity is completely negligible even in measurements of master thread-calibres which have a minimum manufacturing allowance, according to GOST 1623-46, of 4 μ.

EXPERIENCE OF THE NEW METHOD OF STATE CONTROL OF INSTRUMENTS

M. D. Kalennikov

State control of instruments by means of the validity of the test seal does not guarantee their accuracy in use.

Laboratories should control the condition of the measuring equipment by actually check testing instruments without taking into consideration the dates of test seals. The seal itself should not be made valid for a year, two years, or more, but should only show the date of the actual checking of instruments by the State.

In order to gain experience of the possibility of changing over to State control without a validity period for the seal, the Kiev State Control Laboratory for Measuring Equipment carried out the following experiment.

A system of control with actual testing was instituted in the Kiev motor cycle factory and the "Ukrabel'" plant (Ukrainian Cable). Instruments with valid as well as expired seals were tested.

The following results were obtained. In the "Ukrabel'" plant, out of 650 instruments 393 were tested, 155 with valid seals and 238 with expired ones. Out of the "valid" ones, 22 were faulty (14%), and out of the "expired" ones, 8 were faulty (3.4%).

In the Kiev Motor cycle factory 387 instruments were tested. Out of that number 312 had valid seals and 75 had expired ones. Of the "valid" instruments 14 were faulty (4.6%), and of the "expired" ones 7 (9.3%).

From this data it will be seen that the percentage of faulty instruments among the "valid" ones at the "Ukrabel'" plant was lower than that of faulty instruments among the "expired" ones, and at the motorcycle factory it was sufficiently large to be able to neglect a periodic checking of instruments by the State, disregarding the state of seals.

A second check showed no faulty instruments at the motorcycle plant and 2-3 faulty micrometers at the "Ukrabel'" plant.

A changeover to such a method of testing is possible. Its advantage lies in a more reliable method of ensuring accuracy of instruments at enterprises, since with this method the formal sign of reliability, the test seal date, will be replaced by a direct mark, that of the reliability and accuracy of the instrument at the time of testing.

The changeover to this method is possible in the main under the following conditions: rejection of State revenue planning, yearly testing of instruments by the State at enterprises, the extent of testing depending on

the state of supervision exercised over the instruments and condition of their operation, occasional check tests of the accuracy of instruments according to specification.

The present control figure, the total revenue, must be replaced by the indication of the number of enterprises to be checked by the State and the number of instruments subject to testing.

ESTABLISHING A TEMPORARY BRANCH IN A TRADING NETWORK

B. V. Gnilitskii

In 1956, during the functioning of the temporary branch in the Rostov region, Zimovnikov district, one of the separated districts of the region, the work of certifying measures in the trading network was carried out by visiting all the establishments and checking measures on the spot.

The chairman of the district cooperative union instructed the chairmen of all the village and industrial cooperatives to provide transportation for the inspector's local visits. An instructor of the district cooperative union was assigned to accompany the inspector to all the local establishments and take not of the inspector's comments.

The cooperative accounts department made an advance payment. It was agreed that in the future the current advance payments would be made at the rate the technical certificates for each village or industrial cooperative were presented.

In practice, the inspection was carried out as follows. The cooperative transport carried from the local workshop "Remves" to all the required village or industrial cooperatives the standard weights of 500 kg, and a set of weights. On being informed of their arrival at the destination, the inspector and cooperative instructor went there, taking with them portable scales, a comparator, etc. Since there were only two or three unequal arm balances in each place (at the store and in the bakery), the checking did not take long and the standard weights were dispatched the same day to the next place.

Usually, the measures of a local establihsment consist of one or two table scales, 8-12 weights, one or two meters, and one or two measures of capacity. The checking of the weights and measures took some 20-25 minutes; during this time trading had to be interrupted. All the accurate measures were stamped and the rejected ones were taken away or replaced, if possible, from the stock carried by the inspector.

When all the village cooperative weights and measured had been checked, an operation lasting one or one and a half days, a technical certificate was issued and a document compiled in which, in addition to the list of the certified and rejected weights and measures, other shortcomings were noted.

At the completion of the inspection, the chairmen of the district and regional cooperative unions received reports which served as a basis for an instruction on the measuring equipment being issued by the regional cooperative union.

A total of 18 days were spent for checking the whole district cooperative network comprising 4 industrial and 5 village cooperatives, with a total of 148 trading establishments. In this time, 2566 weights and measures were checked and 3240 roubles of State revenue collected.

The described organization of inspection has the following advantages: all the weights and measures of the district trading network were checked; the whole of the measuring equipment of the district cooperative union was listed; the condition of use of all the measuring equipment of the district cooperative union were investigated. Centralized reckoning led to the issue of 9 technical reports only instead of the usual report for each trading establishment. Another positive feature was the achieved economy in expenditure: the travelling costs of two men are considerably smaller than the price of delivery for checking of the measuring equipment from each establishment over a distance of 10 to 70 kms.

Considering the importance of the temporary branches, it would be advisable to call district conferences for the exchange of experiences, taking into account the geographical and climatic conditions of the regions where the temporary branches are set up. Then a technique of operating temporary branches should be worked out.

STATE CONTROL LABORATORIES AND DEPARTMENTAL SUPERVISION

B. N. Vorontsov

State control laboratories for measuring equipment, overloaded as a rule by the simplest type of testing, in which the greater part of the enterprise is not interested, pay very little attention to strengthening the departmental control agencies, limiting themselves to "certifying" measures and instruments used in production.

Left to themselves, without any guidance from the laboratories, the departmental control agencies content themselves with working to the minimum requirements presented to them by the industry and laboratory inspectors. The result is that the work of the industrial measuring instrument laboratories in the majority of cases is limited to checking the measuring equipment according to specifications and graphs established by the agencies of the Committee for Standards, Measures and Measuring Instruments.

Shop measuring-instrument laboratories seldom engage in applying new measuring techniques, improving the methods and means of control, taking an active part in the general technological development, and when they do it is only on a haphazard basis. Nevertheless, all the above functions are basic tasks of the TsIL and other factory agencies of departmental control.

Factory measuring laboratories should become centers of measuring technique and its qualified personnel capable not only of attending to measuring instruments, but also solving authoritatively and correctly from the technical point of view problems connected with measurements.

Unfortunately, despite excellent equipment the TsILs hardly use their opportunities of improving the general technical level of production and occupy a modest position as auxiliary bodies in the general system of technical control of a factory, in essence failing to be laboratories, but becoming places for measuring and passing instruments as "useful" or "useless."

In order to orientate the work of the TsIL correctly, and make the experience of the best enterprises generally available and at the same time raise the standard of the department control agencies, the Gor'ki Laboratory organized a section for Linear and Angular Measurements attached to the Technical Council and comprising, in addition to the Laboratory representatives, heads of TsIL's of the nine largest Gor'ki enterprises.

The function of this section has been defined as follows:

1. Development of a typical plan of organizational measures for TsILs, designed to solve the basic production problems.

2. Discussion of technical comments on proposed specifications and State standards, technical characterization of the working quality of new instruments and tools being produced.

3. Discussion of experimental test results of new measuring instruments and their introduction to other factories.

4. Participation of the section members in approving workers engaged in departmental supervision and in the work of commissions inspecting the work of departmental control.

5. Making the experience of leading enterprises generally available and extending it to other plants.

The first practical results of the section's work were expressed in making a plan of organizational measures for the first six months, consisting of the following: application of new measuring techniques and new, more perfect methods of control; the study of operational qualities of measures and instruments produced in 1956-1957; elimination of reasons for scrapped production; increasing the lifetime of measuring equipment; making technical test result reports as brief as possible; training of personnel and checking the quality of the inspectors' work; exchange of experiences among factories.

Such plans, made with full consideration of actual possibilities, are confirmed by the chief engineers of the plants and then submitted to the Gor'ki laboratory for use as specifications incumbent for TsIL's application, including all the provisions made therein.

All the advanced plans of enterprises submitted to the laboratory were discussed in detail at the above-mentioned section of the Technical Council. Each section member could acquaint himself with the work of other plants and if necessary confer on any desired question.

In the first quarter of 1957, some of the measures envisaged in the plan were carried out. For instance, the test result reports were greatly simplified; experimental work was conducted with the view of applying a new measuring technique; operational qualities of several new instruments were tested.

The section also discussed the experimental results of testing the operational quality of new instruments for checking angle meters, for simultaneous checking of five extensometers of the clockwork type, and for checking bolt threads.

It was found that the instrument for checking angle meters [see Measurement Techniques No. 5 (1957) p. 68] had considerable advantages as compared with the existing models, and it was decided to put it into mass production.

The instrument for checking extensometers is designed for mass checking of extensometers of the clockwork type with divisions of 0.01 mm.

Five extensometers are secured in a carriage along a horizontal contour of a 4° wedge; the carriage is displaced along the wedge by means of a flywheel and pinion which engages in a rack attached to the carriage. The extensometer feelers are adjusted to touch the surface of the wedge. The difference in readings between the standard extensometer and those being checked gives their calibration. The instrument should be used for checking by the comparison method against a calibrated extensometer selected to have a single value error along the whole measuring range. In such an instance the error of the standard extensometer is easily remembered and taken into account when the remaining four extensometers are calibrated.

An instrument for checking bolt threads directly in the workshop was tested in the first quarter of 1957, and gave satisfactory results. The instrument is designed to check external (diameter up to 40 mm) and internal (diameter up to 20 mm) threads made to the second- and third-grade of accuracy.

The checking of the thread is made by means of an exchangeable ring gauge split in two halves, and plug gauge whose zero setting is made with thread calibres. The results of checking are shown by means of red and green electrical indicator lamps. The instrument can check from 1000 to 1200 details per hour; the lifetime of the thread gauges is 10-15 times greater than with the hand-operated method.

It was decided to introduce this method in two plants which mass-produce threaded details; these enterprises undertook to make ten such instruments themselves.

In addition, during the first quarter, the work of inspectors in four factories was certified; the inspectors were carrying out independently the routine checking of measuring equipment.

The work of the section, in the first quarter of 1957, has shown that the cooperation of State laboratories with factory measuring instrument laboratories is most effective when close, businesslike relations are maintained with factory agencies of departmental control with the best possible interchange of experiences.

Such cooperation with the most qualified factory personnel strengthens departmental control and improves measuring technique.

IMPROVED ACTIVITIES OF THE COMMITTEE'S CHECKING AGENCIES

S. L. Mandel'baum

State control laboratories for measuring equipment, in addition to State supervision over measures and measuring instruments, must control the activity of departmental agencies controlling measures and measuring instruments, must control standards and technical conditions, correct measurement of fuel and lubricating materials, study instruments of a new design under working conditions, supervise the work of instrument making and repairing enterprises.

What are the means at the disposal of the Committee's laboratories for fulfilling the tasks entrusted to them?

In the Azerbaidjan SSR, for instance, according to the 1957 plan approved by the Committee, the time spent on State testing of instruments in the Republic amounts to 80% of the total working time, including 48% on checking measures and measuring instruments on List No. 3, which is subject to obligatory checking by the departmental control agencies.

For carrying out all the remaining activities only 20% of the working time is available, of which only 10% is spent on controlling the condition and accuracy of measures and measuring instruments, observing standards and technical conditions which is a most important and new function of the controlling agencies.

With such a time schedule for the working personnel and the concentration of attention on fulfilling the plan of State revenue for checking instruments it is impossible to fulfill efficiently the Committee's instruction No. 617 of October 5, 1955.

In order to improve the present conditions, it is necessary to reorganize the work of the Committee's controlling agencies, taking into consideration the required increase in the volume and improvement in quality of the control and inspection work, and simultaneous decrease in the volume of work of the State control laboratories in checking instruments according to List No. 3.

If the enterprises of the Azerbaidzhan oil industry alone were released from the obligation of presenting their instruments on List No. 3 for State inspection, about 25% of the working time of the personnel engaged in checking instruments would become available for other tasks.

In the second instance, one should examine the advisability of presenting for State inspection instruments on List No. 2 (appendix to the resolution of the Council of People's Commissars of the USSR, No. 1833 of November 16, 1942) as a whole or in part, which consists of State utility services instruments such as electrical, water, and gas meters.

The utility services, which have existed for decades, have organized their work so well that the checking by the State of their instruments produces negligible scrap (about 1% for electrical and water meters).

In carrying out the proposed measures it is advisable to combine the linear and angle measuring group with the group of mechanical measurements, and the group of thermotechnical measurements with that of electrical and magnetic measurements, thus reducing the number of checking groups in laboratories of the I and II categories to three (instead of the existing five), namely, the linear-mechanical, electro-thermotechnical, and radio-measuring groups, and only reducing to two in the laboratories where radio measuring groups do not exist.

In addition to the checking groups, the laboratories should have one powerful control and inspection group staffed by specialists in all types of measurements used in the basic branches of the national economy, which group should ensure an increased volume of work at a high technical level.

ESTABLISHMENT OF INTERDEPARTMENTAL CMI & E WORKSHOPS

A. D. Snagovskii

At present the majority of our country's enterprises have their CMI & E workshops, whose tasks include the operation, repair and departmental supervision of instruments. As a rule, these workshops are small, crammed and badly equipped. Instruments are repaired by handicraft methods in a costly manner, as a result of which the repair of an instrument costs considerably more than the price of a new one. In connection with the reoganization of industrial control, it is expedient to create on the basis of the present small CMI & E workshops powerful interdepartmental shops. Such workshops, on the basis of good equipment, could use efficient labor methods, making the repair of instruments much cheaper, thus increasing the serviceability of checking devices and instruments and considerably reducing the office personnel involved. It would be sufficient to leave at the enterprises operational groups headed by a foreman charged with departmental supervision and operation of control and measuring instruments and automatic devices in the plants.

LITERATURE ON THE REPAIR OF MEASURES AND MEASURING INSTRUMENTS

G. A. Nasonov (Barnaul) notes that efficient operation of measuring instruments and equipment is often made difficult as the result of the lack of recent publication of relevant technical literature. Yet the factory control agencies are in need of handbooks dealing with such questions as correct nomenclature, installation, mounting, and details of the instruments and tools, types and makes of lubrication, composition of cleaning liquids, repairs of universal measuring instruments such as cog, angle gauges, etc.

Recently the factory laboratories have been granted the right to repair and test all their measuring instruments. The instructions attached to the instrument, however, only give a general idea of the possible faults and their clearing.

The lack of the required instructions and handbooks often leads to damaging of instruments due to incorrect installation or unskilled handling of them.

It is necessary to issue without delay books on the operation, repair and adjustment of measuring instruments and tools, including instructions and handbooks.

Appropriate organizations should demand that the measure and instrument-making plants send detailed descriptions with illustrations.

P. A. Plaskeev, head of the Yakutsk State measuring instrument control laboratory, writes that the workers in instrument repair enterprises are deprived of the opportunity of studying by themselves the theory of measures and measuring instruments, and obtaining thorough practical experience due to the lack of relevent technical literature. Neither is there any data on the interchange of experience among the leading instrument repair enterprises of our country. Yet the need for such literature among the workers in instrument repair enterprises and various departmental laboratories is great.

Editorial Note. The questions raised by G. A. Nasonov and P. A. Plaskeev are very important. Technical literature publishing houses (Mashgiz, Standardtgiz, etc.), must plan the issuing of books, pamphlets, handbooks, and instructions on the operation, repair, and adjusting of measures and measuring instruments.

As far as this editorial board is concerned, it requests readers to send articles on this subject for publication in the journal.

IN THE COMMITTEE OF STANDARDS, MEASURES AND MEASURING INSTRUMENTS

I. NEW NORMATIVE DOCUMENTS ON MEASURES AND MEASURING INSTRUMENTS APPROVED BY THE COMMITTEE

(Registered in July-December, 1957)

New Standards

GOST 215-57. Thermometers, laboratory mercury in glass. Replacing GOST 215-41.

GOST 574-57. Scales, table. Replacing GOST 574-49.

GOST 895-57. Densimeters with a pipette, for storage batteries. Replacing GOST 895-41.

GOST 1289-57. Oil densimeters, glass. Replacing GOST 1289-57.

GOST 4381-57. Micrometers, lever type. Replacing GOST 4381-48.

GOST 8517-57. Instruments for checking dimensions (diameters) of details in the course of grinding on a circular grinder. Types. Basic technical requirements. First issue.

GOST 8550-57. Thermal units. Replacing OST VKS 6259.

GOST 8623-57. Resistances, multiplier calibrated. Technical requirements. Replacing GOST 1845-52, GOST 3043-53 in the part referring to multipliers, and GOST 1827-47.

GOST 8624-57. Thermometers, manometric. Replacing GOST 2703-51, GOST 2873-45, and GOST 3195-46.

GOST 8625-57. Manometer, manovacuum-meters, and vacuum-meters, indicating, for general application. Replacing GOST 1011-53 and GOST 7331-55.

New Instructions for Testing Measures and Measuring Instruments

Instruction 29-57 for testing syrup dosimeters.

Instruction 47-57 for testing table scales. Replacing instruction 9-49 of the former Kommerpribor (commercial instruments).

Instruction 59-57 for testing liter measures. Replacing instruction 61-42 of the former Kommerpribor.

Instruction 83-57 for testing metal rules. Replacing instruction 83-55 of the former Kommerpribor.

Instruction 104-57 for testing plane-parallel glass plates. Replacing instruction 104-53 of the former Kommerpribor.

Instruction 123-57 for testing dial snap gauges with divisions of 0.01 mm.

Instruction 124-57 for testing dial depth gauges.

Instruction 135-57 for testing micrometers. Replacing instruction 135-53 of the former Kommerpribor.

Instruction 136-57 for testing micrometer hole gauges. Replacing instruction 136-53 of the former Kommerpribor.

Instruction 137-57 for testing micrometer depth gauges. Replacing instruction 137-53 of the former Kommerpribor.

Instruction 194-57 for testing phase meters. Replacing technical directions No. 46 of the former Kommerpribor.

Instruction 197-57 for testing magnetic thickness gauges.

Instruction 256-57 for testing glass measuring burettes of chemical nonautomatic gas analyzers. Replacing technical directions No. 13 of the former Kommerpribor.

Methodological Directives for Testing Measures and Measuring Instruments Approved by the Committee's Technical Department

Methodological directive No. 158 for testing second-grade heavy piston gauges (class 0.05) and third-grade (class 0.2) gauges with a balanced piston (MP-2.5). Replacing methodological directive No. 148 of the former Kommerpribor.

Methodological directive No. 159 for testing a scale with cross hairs Shk2.

Methodological directive No. 160 for testing measuring waveguide lines.

Methodological directive No. 161 for testing attenuation boxes.

Methodological directive No. 162 for testing autocollimation instruments, type KPU-1.

II. MEASURES AND MEASURING INSTRUMENTS APPROVED BY THE COMMITTEE FOR USE IN THE USSR ON THE BASIS OF STATE TEST RESULTS

Single and double dc laboratory bridge, trademark MOD-54. Formerly of the Ministry of Aircraft Industry of the USSR. State Register No. 1088-57.

Three-phase power meters types SAZ and SAZU, trademark I43 of the Moscow Regional Council of National Economy. State Register No. 1090-57.

Three-phase power meters, types SA4 and SA4U, trademark I45 of the Moscow Regional Council of National Economy. State Register No. 1091-57.

Slide wire bridges, trademark P38, complete with electric cells for testing specific conductivity of electrolytic aqueous solutions, trademark Kh38 of the Krasnodar Sovnarkhoz (Council of National Economy). State Register No. 1092-57.

Wavemeters, resonance, trademark I332, of the former Ministry of Aircraft Industry of the USSR. State Register No. 1093-57.

Saccharimeters, universal, trademark SU-2 of the Ministry of Provisions Industry of the UkSSR. State Register No. 1094-57.

Combined goniometer-spectrometers, trademark GS-30 of the former Ministry of Defense Industry. State Register No. 1095-57.

Tube test set, trademark IL-14, of the former Ministry of Radiotechnical Industry. State Register No. 1096-57.

Signal generator, trademark 51-I of the Lithuanian Sovnarkhoz. State Register No. 1097-57.

Variable frequency oscillator, trademark NG-53, the Electrorem factory, Rostovenergo, State Register No. 1098-57.

Methane detector, portable, optical, trademark OB2301 of the Leningrad Sovnarkhoz. State Register No. 1099-57.

Mega-megohmmeter, trademark F57 of the Kiev Sovnarkhoz. State Register No. 1100-57.

Volt-ammeters, trademark Ts315 of the Krasnodar Sovnarkhoz. State Register No. 1101-57.

Ammeters and microammeters, moving-coil rack mounted, trademark M 131/1 and M 131 of the Leningrad Sovnarkhoz. State Register No. 1102-57.

Ammeters, moving-coil, portable, miniature, trademark M 109 of the Leningrad Sovnarkhoz. State Register No. 1103-57.

Voltmeters, moving coil, portable, miniature, trademark M 109 of the Leningrad Sovnarkhoz. State Register No. 1104-57.

Frequency meters, ferrodynamic, rack mounted, trademark D210, of the Leningrad Sovnarkhoz. State Register No. 1105-57.

Volt-ammeters, portable, miniature, trademark Ts20 of the Omsk Sovnarkhoz. State Register No.1106-57.

Megohmmeter, electronic, trademark MON-3 of the Estonian Sovnarkhoz. State Register No. 1107-57.

Single-phase electricity meters, trademark SO-2 of the Moscow Regional Sovnarkhoz. State Register No. 1108-57.

Ammeters, moving-coil, rack mounted, shake-, vibration-, and shock-proof, trademark M150, M160, M170 and M180 of the Leningrad Sovnarkhoz. State Register No. 1109-57.

Voltmeters, moving-coil, rack mounted, shake-, vibration-, and shock-proof, trademark M150, M160, M170 and M180 of the Leningrad Sovnarkhoz. State Register No. 1110-57.

Volt-ammeters, rectifying, portable, trademark Ts51 of the Kiev Sovnarkhoz. State Register No.1111-57.

Multirange rectifying instruments, portable, trademark Ts52 of the Kiev Sovnarkhoz. State Register No. 1112-57.

Ammeters, moving-iron, rack mounted, trademark E30/2 of the Krasnodar Sovnarkhoz. State Register No. 1113-57.

Voltmeter, moving-iron, rack mounted, trademark E30/2 of the Krasnodar Sovnarkhoz. State Register No. 1114-57.

Device for testing hard-magnetic materials, trademark U-541 of the Kiev Sovnarkhoz. State Register No. 1115-57.

Ratio-meters, shaped, trademark LPr-53 of the L'vov Sovnarkhoz. State Register No. 1117-57.

Device for measuring the temperature in grain driers, trademark DKTSU-1M of the Kiev Sovnarkhoz. State Register No. 1118-57.

Interferometers, horizontal, contact type IKPG, trademark PIU-3 of the Moscow Sovnarkhoz. State Register No. 1119-57.

Microscopes, measuring, trademark MPB-2B of the Khar'kov Sovnarkhoz. State Register No. 1120-57.

Wave-meter of medium accuracy, trademark 35-IM of the Lithuanian Sovnarkhoz. State Register No. 1121-57.

Wave-meters, heterodyne type, trademark VG-526, VG-527, and VG-528 of the L'vov Sovnarkhoz. State Register No. 1122-57.

Microbalances, torsion type, trademark MV-1 of the Moscow Sovnarkhoz. State Register No. 1123-57.

Gas analyzers, chemical, portable, trademark GKhP-3M of the Moscow Sovnarkhoz. State Register No. 1124-57.

Stopwatch, with two pointers, trademark 51SD of the Moscow Sovnarkhoz. State Register No. 1125-57.

Contact psychorometer, combined, trademark TK-10 of the Moscow Regional Sovnarkhoz. State Register No. 1126-57.

Wave-meters, resonance, trademark UVR-1 and UVR-2 of the L'vov Sovnarkhoz. State Register No. 1127-57.

Thermometers for oil products, trademark TN-8 of the Moscow Regional Sovnarkhoz. State Register No. 1128-57.

Mean medical sets of test spectacle lenses, trademark MNS of the Khar'kov Sovnarkhoz. State Register No. 1129-57.

Single-phase electricity meters, trademark SO/M of the L'vov Sovnarkhoz. State register No. 1130-57.

Ammeters, trademark M364 of the Krasnodar Sovnarkhoz. State Register No. 1131-57.

Voltmeters, portable, trademark Ts23 of the Omsk Sovnarkhoz. State Register No. 1132-57.

Voltmeters, rack mounted, trademark Ts24 of the Omsk Sovnarkhoz. State Register No. 1133-57.

Vertical gauges for horizontal telescope calipers, trademark PP-2 of the Leningrad Sovnarkhoz. State Register No. 1134-57.

Galvanometers, portable, trademark M-117 of the Leningrad Sovnarkhoz. State Register No. 1135-57.

Fluxmeters, trademark M-119 of the Leningrad Sovnarkhoz. State Register No. 1136-57.

Potentiometers, dc, trademark P-375 of the Krasnodar Sovnarkhoz. State Register No. 1137-57.

Gas analyzers, for oxygen, trademark DPG-5-52 of the Ministry of Chemical Industry. State Register No. 1138-57.

Butter packing unit, trademark M-367 of the Leningrad Sovnarkhoz. State Register No. 1139-57.

Sets of individual dosimeters, trademark KID-1 of the Byelorussian Sovnarkhoz. State Register No. 1140-57.

Tube millivoltmeters, trademark MVL-3 of the Estonian Sovnarkhoz. State Register No. 1141-57.

Spring measuring heads, trademark 1-IGP of the Leningrad Sovnarkhoz. State Register No. 1142-57.

Cable instruments, trademark KPL-3 of the Ministry of Communications. State Register No. 1143-57.

Condensers, air, trademark P-533 and P-534 of the Kiev Sovnarkhoz. State Register No. 1144-57.

Gas analyzers, magnetic, for oxygen, trademark MGK-2 of the Ministry of Chemical Industry. State Register No. 1145-57.

Voltmeters, rack mounted, trademark Ts-27 of the Omsk Sovnarkhoz. State Register No. 1146-57.

Millivoltmeters, tube, trademark MVL-2M of the Estonian Sovnarkhoz. State Register No. 1147-57.

Micro-x-ray meters, medical, trademark MRM-1 of the Byelorussian Sovnarkhoz. State Register No. 1148-57.

Voltmeters, trademark M-364 of the Krasnodar Sovnarkhoz. State Register No. 1149-57.

III. INSTRUCTIONS AND METHODOLOGICAL DIRECTIVES FOR TESTING MEASURES AND MEASURING INSTRUMENTS CANCELLED BY THE COMMITTEE

Instruction 5-48 for testing electric-contact transmitters.

Instruction 6-48 for testing optico-mechanical instruments.

Instruction 44-48 for testing calibres for shafts and holes.

Instruction 45-48 for testing thread measuring devices.

Instruction 50-48 for testing radial gauges and feeler gauges.

Instruction 66-43 for testing measuring barrels, autocisterns, and railway cisterns.

Instruction 67-44 for testing medical mixers.

Instruction 72-47 on establishing a water equivalent for a calorimeter.

Instruction 76-49 on testing instruments which determine hardness by the method of elastic bouncing.

Methodological directive No. 5 for testing mercury barometers.

Methodological directive No. 6 for testing barometers, aneroidal and altimeter type.

Methodological directive No. 23 for testing mechanical power indicators.

Methodological directive No. 42 for testing permeammeters and ferrometers.

Methodological directive No. 64 for testing pyrometers.

Methodological directive No. 75 for testing frequency meters and frequency-measuring bridges at audio-frequencies.

Methodological directive No. 85 for testing optical color pyrometers.

Methodological directive No. 92 for testing sample electricity meters.

Methodological directive No. 94 for testing sample heavy manometers, first grade, up to 2000 kg/cm^2.

Methodological directive No. 100 for checking GOI sensitometers.

Methodological directive No. 102 for testing electrical gas analyzers type 23UK-21.

Methodological directive No. 105 for testing semi-automatic petrol pumps type BMP.

Methodological instruction No. 133 for testing gas analyzers type GVVB and GVVM.

IV. MEASURES AND MEASURING INSTRUMENTS EXCLUDED FROM THE STATE REGISTER

Microammeters, trademark M91. State Register No. 448.

Microscopes, measuring, MBP-2. State Register No. 459.

Medical sets of test spectacle lenses. State Register No. 812.

Devices IP-4. State Register No. 950.

Millivoltmeters, recording, rack mounted, shaped, trademark MSShChPr-54. State Register No. 561.

The production of recording millivoltmeters MSShChPr-54 is forbidden from January 1, 1959.

DISSERTATIONS ON METROLOGY AND MEASURING TECHNIQUE DISCUSSED IN 1956 AND 1957 AT THE D. I. MENDELEEV ALL-UNION SCIENTIFIC RESEARCH INSTITUTE ON METROLOGY

For the Degree of Bachelor of Technical Sciences

M. C. Pedan. Development and investigation of an absolute method of measuring the speed of an air stream and determining coefficients of sample speed tubes.

N. L. Amatuni. Measurement of mutual inductance at low frequencies for metrological purposes.

N. P. Grudinkina. Determination of water purity by means of ultraviolet spectrophotometry.

A. I. Martsinyak. Development of the theory and equipment and determination of the value of gravity acceleration by an absolute method of a falling rod in vacuum.

V. P. Koronkevich. Air dispersion in the visible part of the spectrum.

A. A. Ershov. Measurement of the hardness of nonmetallic materials.

N. N. Ergardt. Methods for improving accuracy of measurements of temperatures in the region of 300-1600°C by means of precious metal thermocouples.

V. A. Kovalevskii. New standard objective spectrometric installation.

V. V. Nalimov. Differential study of errors in spectral and chemical analysis by applying mathematical statistic methods.

O. I. Sumbaev. Construction of a two-meter crystal diffraction spectrometer and its application for investigating gamma spectra.

P. T. Prokof'ev. Magnetic gamma spectrometer with a raised luminosity.

CHANGES IN CURRENT INSTRUCTIONS FOR TESTING MEASURES AND MEASURING INSTRUMENTS

N. M. Staroverov

Recently, the Committee for Standards, Measures and Meqsuring Instruments has introduced a number of changes and additions to the current normative documents on testing measures and instruments.

In Instruction 22-56 for testing gas meters, the permissible errors of readings have been differentiated for house meters with measuring bellows and a normal rate of flow up to 6 m^3/hr, and the following limits established: for meters in use the error at any rate of flow must not exceed ± 5% (after the one and a half years of guaranteed operations laid down in GOST 5364-57).

When the above meters are repaired, their reading error must not exceed ± 3% at rates of flow between 50% and 100% of the maximum and ± 4% at a rate of ± 10%.

The reading error of meters newly produced remains the same.

The permissible drop in pressure at a nominal rate of flow has been changed for above meter from 10 mm head of water to 11 mm head of water.

In addition, the Committee established a time limit for a periodic state inspection of these meters which must not exceed 5 years (according to the current instruction, no time limit for obligatory testing is fixed).

Instruction 20-56 for checking water meters and their test equipment now includes a requirement for changing the head of water in the measuring tanks (chambers) according to the changed volume of water in the tanks.

In this connection the table on page 3 of Appendix 1 is supplemented by a sixth column, as follows:

Change of the head of water in mm, corresponding to a change in volume of 1 in^3 (not less)
6
3
1.5
0.3
0.15

In order to extend the region of application of normal diaphragms the values of Reynolds limiting numbers have been lowered and, consequently, Table 1, page 68, of rules 27-54 on the application and testing of flow meters with normal diaphragms, nozzles and Venturi tubes has been superseded by the following table:

m	Re_{np}		m	Re_{np}	
	for diaphragms	for nozzles & Venturi nozzles		for diaphragms	for nozzles & Venturi nozzles
0.05	23000	60000	0.40	130000	165000
0.10	30000	66000	0.45	160000	180000
0.15	45000	75000	0.50	185000	190000
0.20	57000	90000	0.55	210000	200000
0.25	75000	105000	0.60	240000	200000
0.30	93000	125000	0.65	270000	200000
0.35	110000	140000	0.70	300000	—

In instruction 122-53 for checking gear-tooth verniers, the requirements of the technique of testing that the sides of the lip measuring surfaces must be rectilinear and parallel have been changed.

It is recommended to carry out the checking of the linearity of lip measuring surfaces in two mutually perpendicular directions with the aid of a French curve rule. No light should be seen with the naked eye between the straight edge of the rule and the measured surface.

To ensure that the lips are parallel they are placed close together and then there should be no light observable between them.

The checking of the lip surfaces by means of the altitude slide is cancelled.

A Committee order clarifies instruction 69-56 on testing weights, with respect to technical first-class weights. The checking of the above weights (both steel and copper alloy) against first-grade copper alloy weights must be carried out without taking into account corrections for the action of the aerostatic force.

When technical first-class weights are checked by means of sample first-grade steel weights, without taking into account the difference in the action of the aerostatic force, the sample weights should be supplemented by milligram weights of the first-grade (without taking them into account when the mass of the weight is calculated), as shown in the table given below.

Weights of 50 g and smaller are not supplemented by additional weights.

In the certificates of the checked technical weights it should be stated that the assumed density of the material was taken at 8.4 g/cm^3.

Nominal value of the first-grade steel weight mass, kg.	Value of the first-grade milligram weights added to the scale with the sample weights, mg.
20	200
10	100
5	50
2	20
1	10
0.5	5
0.2	2
0.1	1

In order to simplify the testing of audio frequency oscillators, a table is appended to instruction 208-54. The table gives the permissible readings of a standard voltmeter connected to oscillator ZG-10 (the most common audio frequency oscillator), which eliminates the necessity of calculating errors of the output voltage and the actual value of the divider voltage ratio.

This table is given in the Appendix to the instruction in the following form:

Table of Permissible Readings of a Standard Voltmeter Obtained When Checking the Potential Divider of a Type ZG-10 Oscillator

Step being checked	Reading of stand. voltmeter at each step			Actual value of voltage ratio	
	0, db	step being checked		from	to
		from	to		
0	60	60	60	0	0
1	60	51.6	55.4	1.3	0.7
2	60	46.1	49.4	2.3	1.7
3	60	41.0	44.0	3.3	2.7
4	60	36.6	39.2	4.3	3.7
5	60	32.6	34.9	5.3	4.7
6	60	29.0	31.1	6.3	5.7
7	60	25.9	27.75	7.3	6.7
8	60	23.05	24.7	8.3	7.7
9	60	20.6	22.05	9.3	8.7
10	60	18.3	19.6	10.3	9.7
10	60	17.3	20.8	10.8	9.2
20	60	5.47	6.58	20.8	19.2
30	60	1.73	2.08	30.8	29.2
40	60	0.55	0.66	40.8	39.2
50	60	0.173	0.21	50.8	49.2
60	60	0.055	0.066	60.8	59.2
70	60	0.0173	0.021	70.8	69.2
80	60	0.0055	0.0066	80.8	79.2
90	60	0.0017	0.0021	90.8	89.2

Accordingly, the third paragraph of page 25, instruction 208-54, has been changed to read, "The output is adjusted to give the maximum permissible round figure output voltage for the oscillator being checked (60 v for the ZG-10 oscillator) as read on the standard voltmeter and the subsequent readings of the voltmeter noted."

BOOK REVIEWS

N. M. Shchapov, "Hydrometry of Hydrotechnical Constructions and Hydraulic Machines" (Gosenergoizdat, Moscow-Leningrad: 1957) 237 pages, 269 illustrations, price 16 r. 35 k.

This book of some 25 sheets consists of four parts. The first, general, part contains the history of the development of installation investigations in the USSR, i.e., investigations of hydrotechnical constructions and hydrolic machines.

The author divides hydrometry into three branches: the river, laboratory, and installations hydrometry. The book deals with the latter, which the author considers the most recent and least-established, branch.

The second part of the book deals with point methods of measuring the rate of flow by means of hydrometric vanes, flow tubes, and other less common instruments. The whole field of hydrometric measurements and working out of data is covered step by step. The point and branching (integrational) methods of measuring are compared, the application of single vanes and rows of horizontal and vertical swivelling vanes are cited. Considerations for the choice of measuring folds (streaming, straightening, and restricting) and their applications to measurement are given. Numerous examples of rate-of-flow measurements at hydroelectric stations are given. Special attention is paid to raising the accuracy of measurement and calculations with relevant suggestions on the subject. Only graphical methods of approach are given for open cross sections (without a head) (p. 80 and further), whereas there exists an analytical method which is less labor-consuming.

In analyzing the accuracy of hydrometric methods, the author rightly points out that the vane method of measuring the rate of flow is more accurate than generally assumed.

The third part of the book deals with, what the author calls, "integral" means of measuring the rate of flow: wears, normal diaphragms, nozzles, Venturi tubes, and many others. Helical flowmeters most commonly used at hydropower stations, are dealt with in the greatest detail.

Giving a positive evaluation of the possibility of using the pressure difference in a helix (p. 157) for measuring the rate of flow, the author notes that the question to what extent the coefficient $\underline{k}$ in equation $Q = k\sqrt{h}$ remains constant with a changing head is not yet clear. It is therefore necessary to recalibrate the flowmeter for various heads, which complicates the application of flowmeters operating on the pressure difference principle.

From the calibration data obtained at the Tsimlyanskaia hydroelectric power station at heads of 14-21 m, as well as from theoretical considerations, it can be considered that the value of coefficient $\underline{k}$ remains practically constant at changing heads.

There is no reason (p. 163) for limiting the connection of the differential manometer to the first and second quarters of the measuring helix; experience has shown that any position of the branching points is as good.

In examining the helix as a flowmeter (p. 161) the author mentions several types of differential manometer- flowmeters used at water power stations and proceeds to describe them. It should be noted that these instruments very often fail when working with dirty water. It is necessary to elucidate this question still further and design more stable instruments.

The author doubts (p. 190) the expediency of applying the hydraulic shock method of measuring. It would appear that even this method with improved instruments can be applied especially in long straight pipes.

In the fourth and concluding part, a summary is made and, in particular, the attention of designers is rightly drawn to the necessity of providing facilities for measuring the rate of flow for calibration purposes, when designing water power stations.

All the basic hydrometric methods are critically and systematically reviewed in N. M. Shchanov's book, which will greatly facilitate the work of investigators and engineers.

The book describes fully both Soviet and foreign experience in the field, showing that in many spheres the achievements of Soviet science surpass those of foreign countries. Much in this respect has been done by VIGM, ORGRES, and other organizations, and also by the author of the book, one of the pioneers in hydrometry, hydrolic construction and machines.

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Ia. N. Flekser